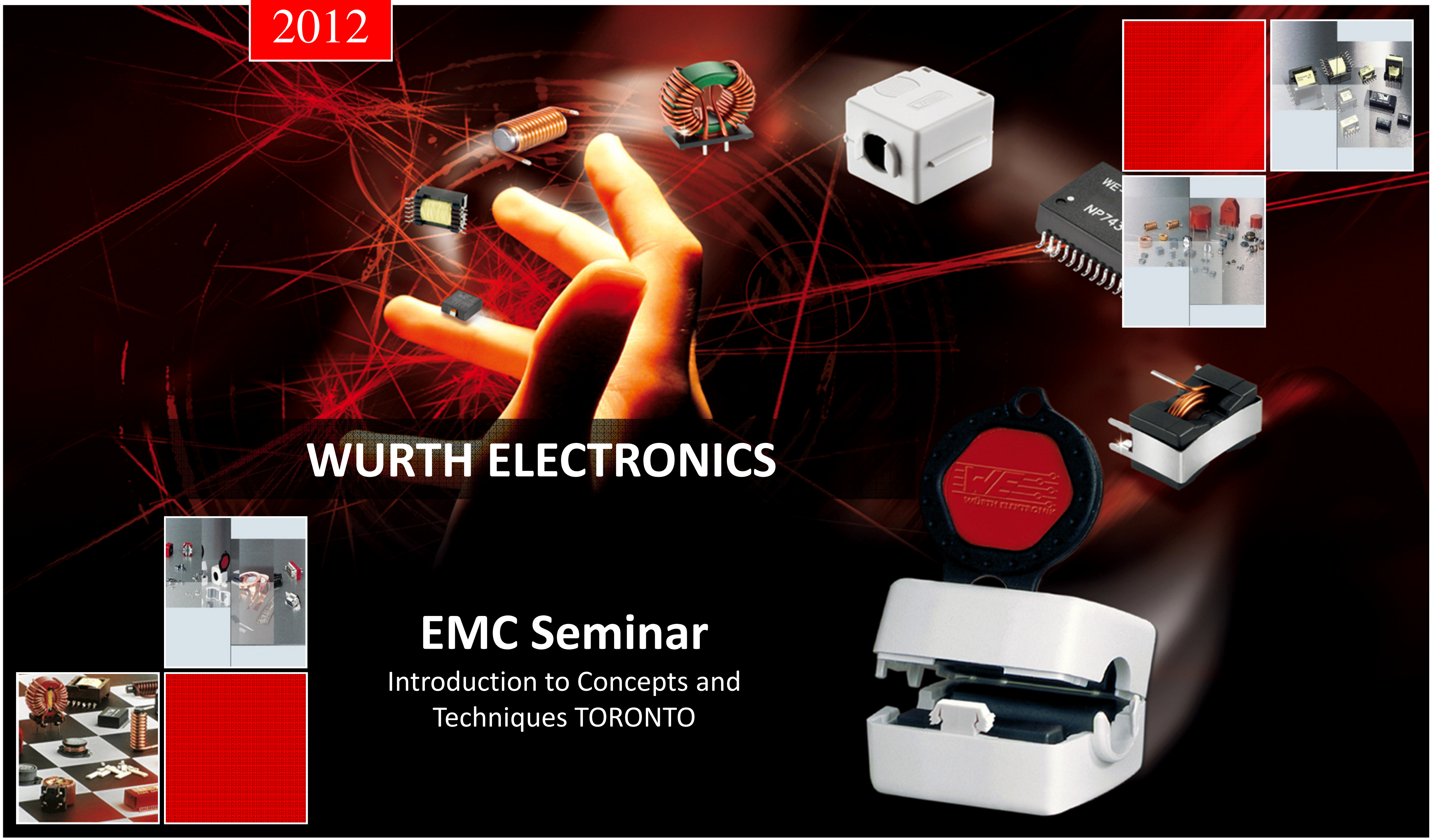
2012



WURTH ELECTRONICS

EMC Seminar

Introduction to Concepts and Techniques TORONTO

Agenda

Magnetic Materials / Inductors

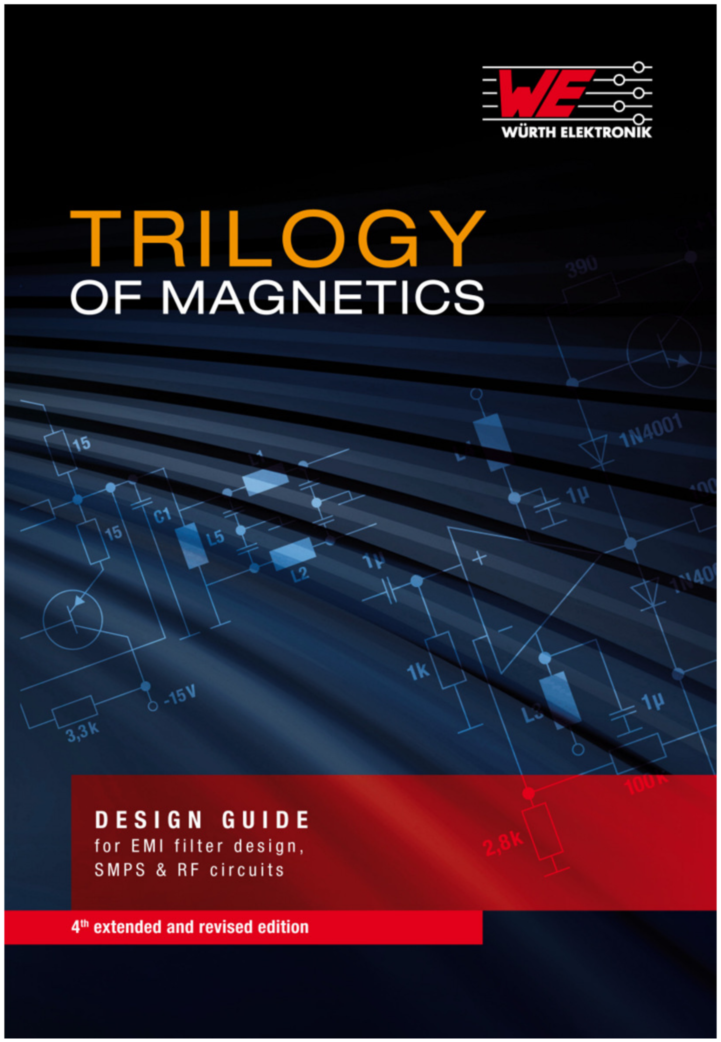
Commom Mode Filters

Chip Bead Ferrites

Shields

TRILOGY OF MAGNETICS

Supplement Material to Today‘s Seminar



- 1. Basic Principles of Magnetics
- 2. Magnetics Components
- 3. Filter Circuits
- 4. Applications

  → concrete examples on more than 300 pages

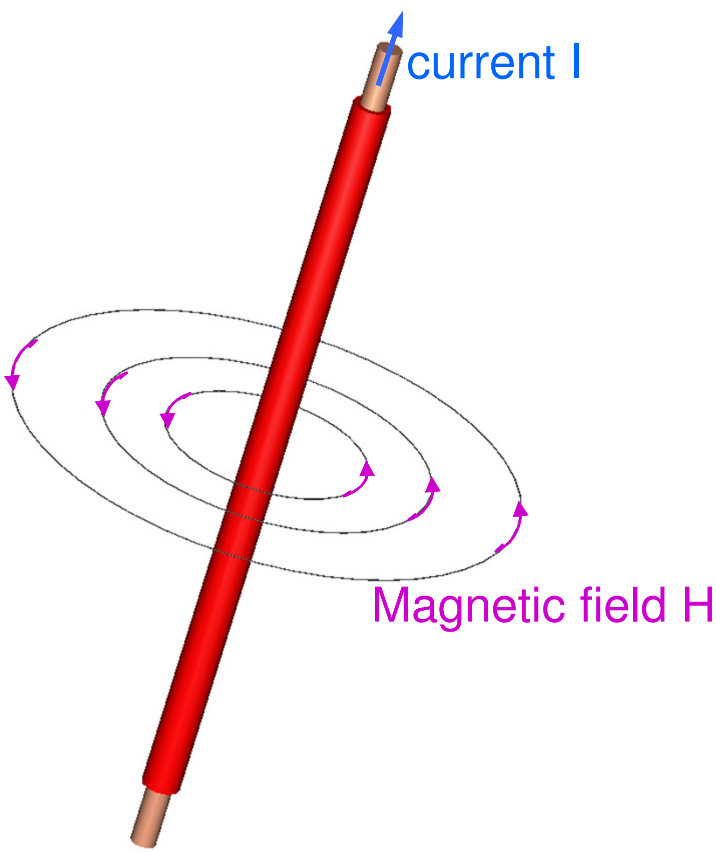
MAGNETIC MATERIALS

AND

INDUCTORS

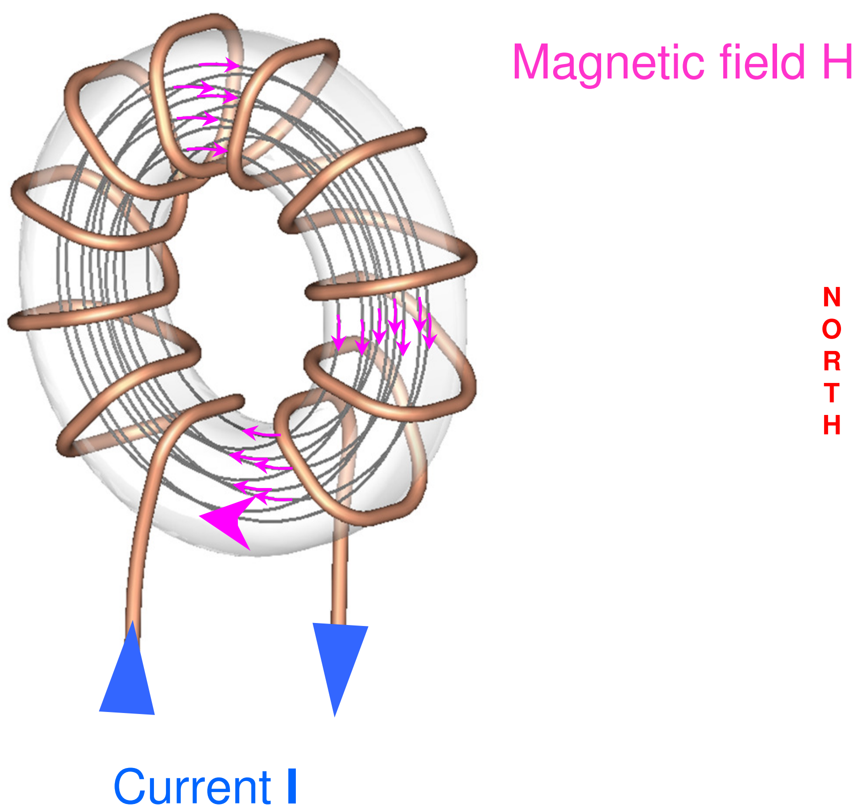
The Magnetic Field (H)

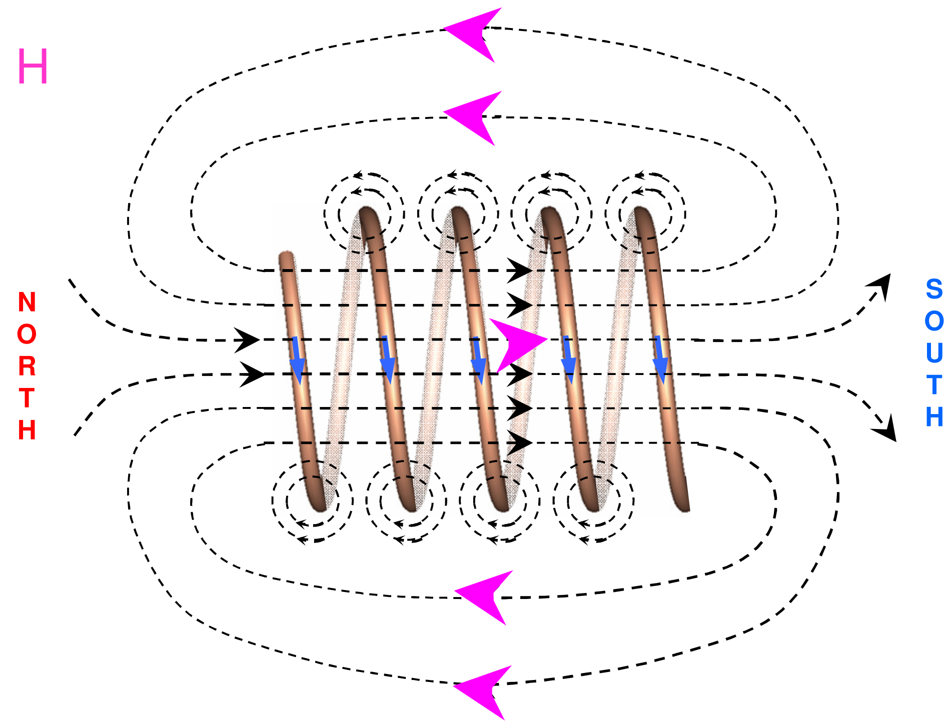
When current flows through a wire it generates a magnetic field



Field model

The Inductor and its Magnetic Field





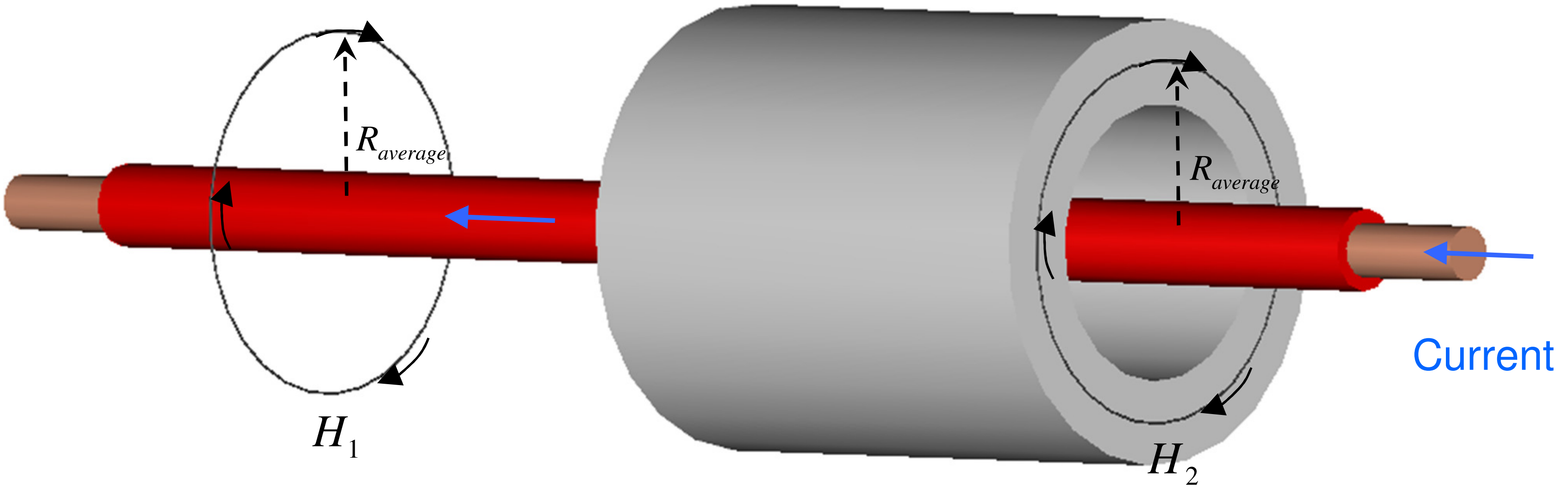
Many EMC solutions consist of inductive components

Materials Used to Make Inductors

Iron Alloys	Fe + Other materials

Ferrites	Ni / Mn + Zn

Magnetic H and B Fields



$$H_1 = H_2 = H = \frac{I}{2 \cdot \pi \cdot R_{average}}$$

$$B_1 \; \boxed{\begin{matrix} \neq \\ ? \\ = \end{matrix}} \; B_2$$

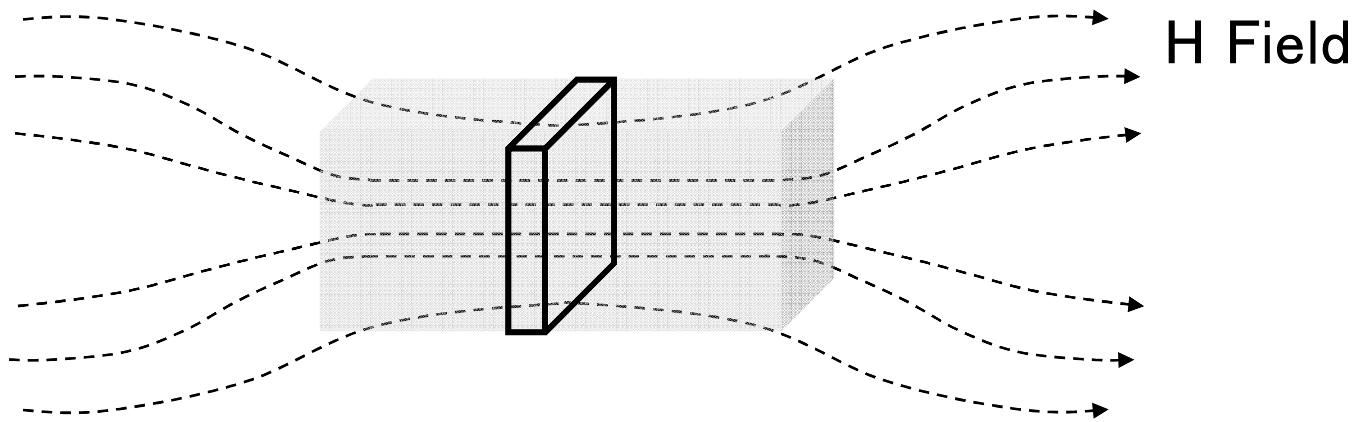
$$B = \mu_o H$$

Permeability

Permeability

Describes the capacity of concentration of the magnetic flux in the material

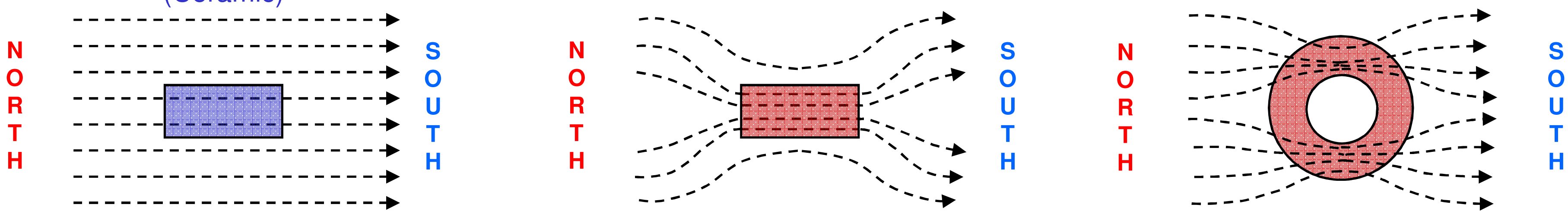
It is a factor of the energy needed to magnetize a material (i.e. magnetically align dipoles)



$$B = \mu_o H$$

Permeability

Air (Ceramic) | Rod core ferrite | Toroidal ferrite core



Induction in air:

$$B = \mu_0 \boxed{\cdot\, \mu_r} \cdot H$$

Linear function because μr = 1

$$B = \mu_0 \cdot H$$

Induction in Ferrite:

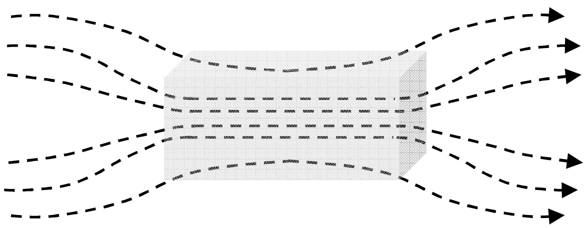
$$B = \mu_0 \cdot \boxed{\mu_r} \cdot H$$

Relative permeability is non-linear

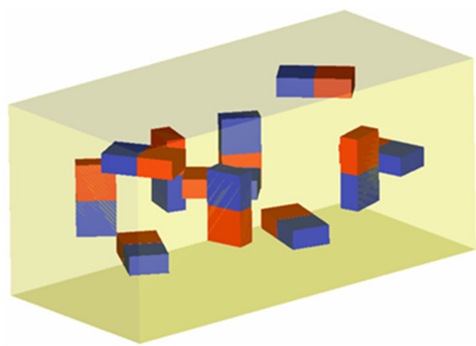
Material **Frequency** **Temperature**

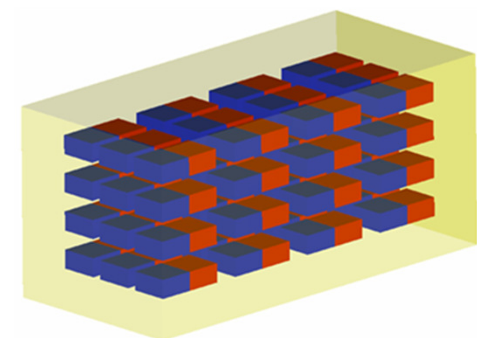
Current **Pressure**

Magnetic Materials



H Field

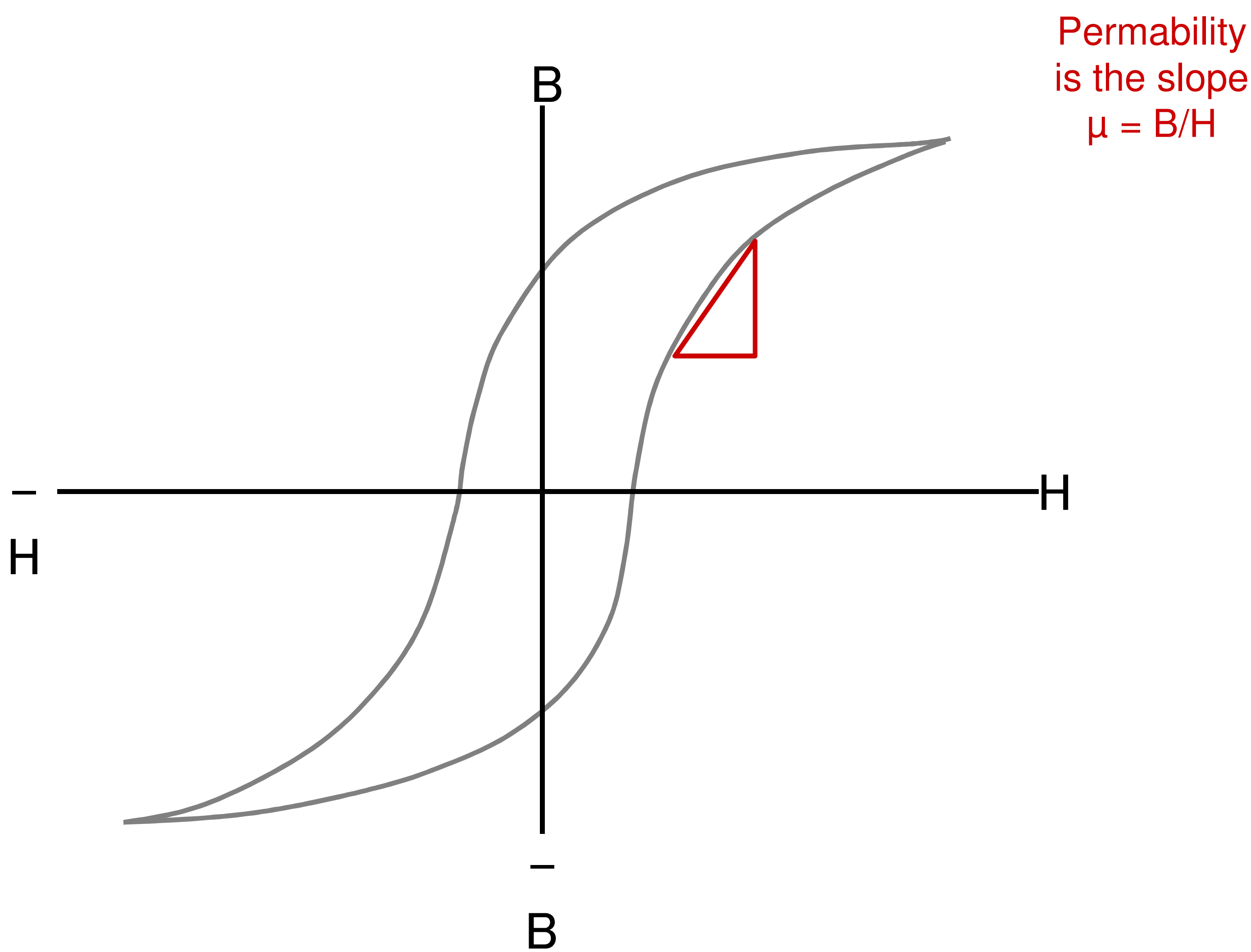




Non-magnetic | Soft-magnetic | Hard-magnetic

Insulators | Ferrites | Fe Alloys

Hysteresis Graph



Soft Ferrites (Have low losses at high frequencies)

- NiZn and MnZn ferrites can be easily magnetized and demagnetized **without dissipating much energy** (hysteresis loss)
- Hysteresis loss is a component of the total core loss.
- Another component of total core loss are Eddy currents which leak useful magnetizing energy
- MnZn has a higher permeability and saturation induction than NiZn
- NiZn has higher resistivity than MnZn. (NiZn works well above 1 MHz)

Hard Ferrites (Have high losses in general)

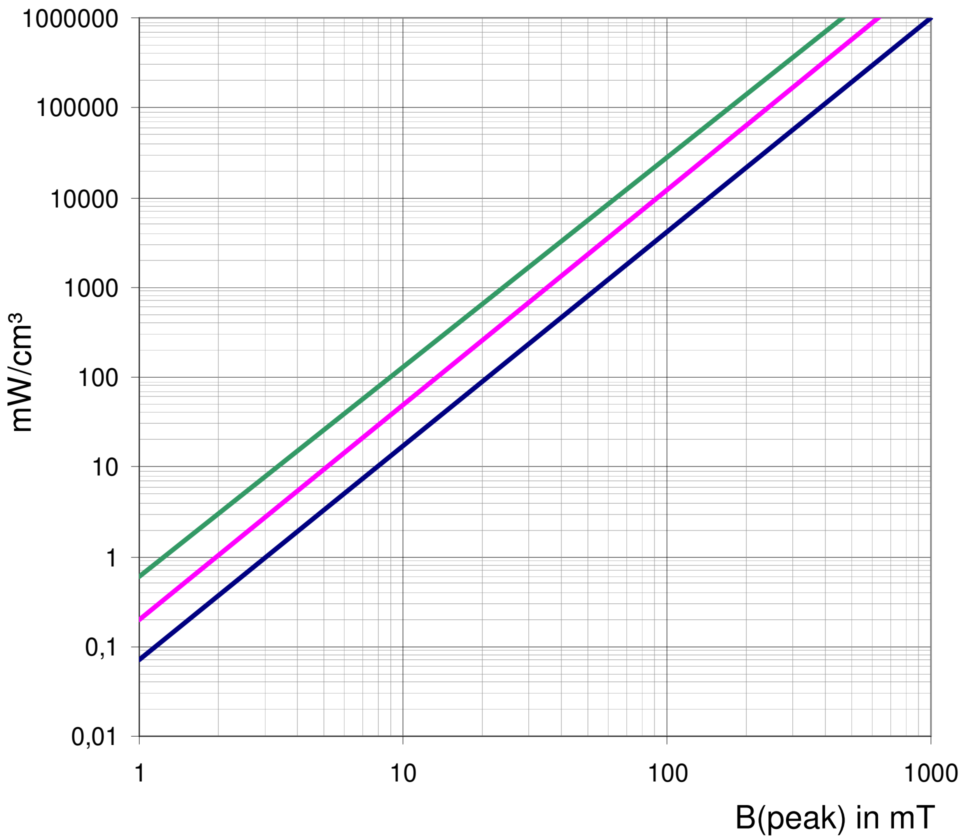
- Hard ferrites cannot be easily magnetized and demagnetized. They need a substantial amount of energy change the direction of the magnetization (high hysteresis loss)
- Iron-based ferrites have the general formula MO-Fe2O3 where M is a divalent ion such as Fe, Ni, Cu, Mg, Mn, Co, Zn or Li.
- The are great conductors of magnetic flux well and have a high magnetic permeability
- They store (handle) stronger magnetic field than soft ferrites
- Relatively, they have low resistivity

Core losses

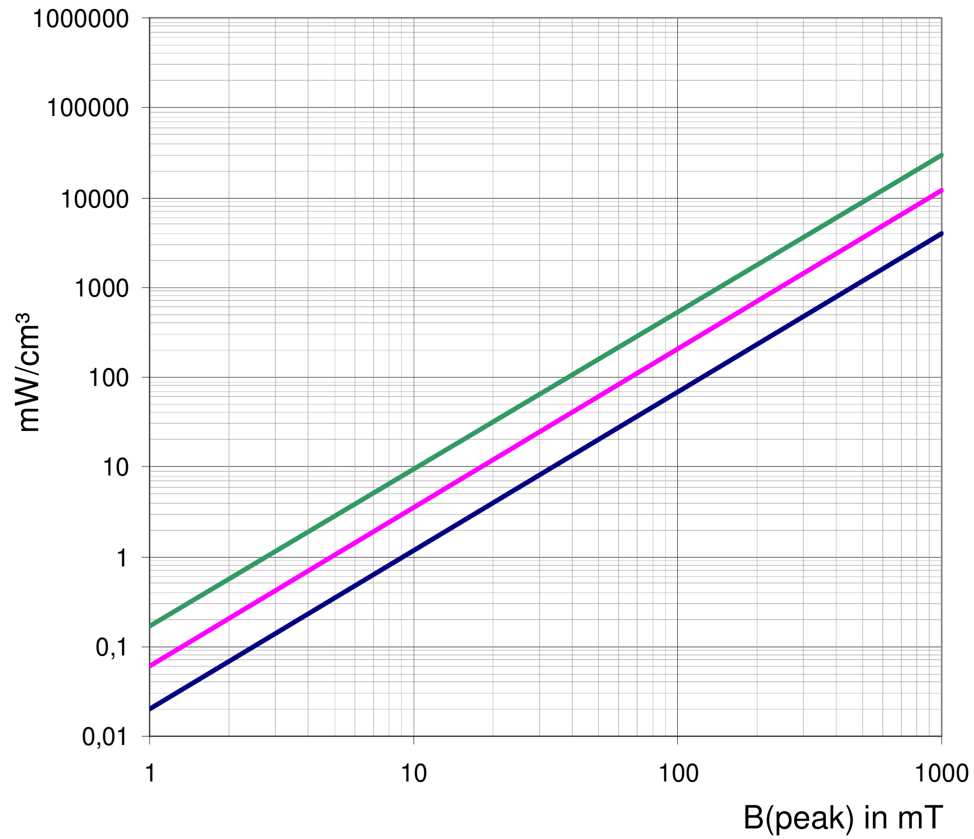
Comparing materials

500KHz
250KHz
100KHz

Iron powder



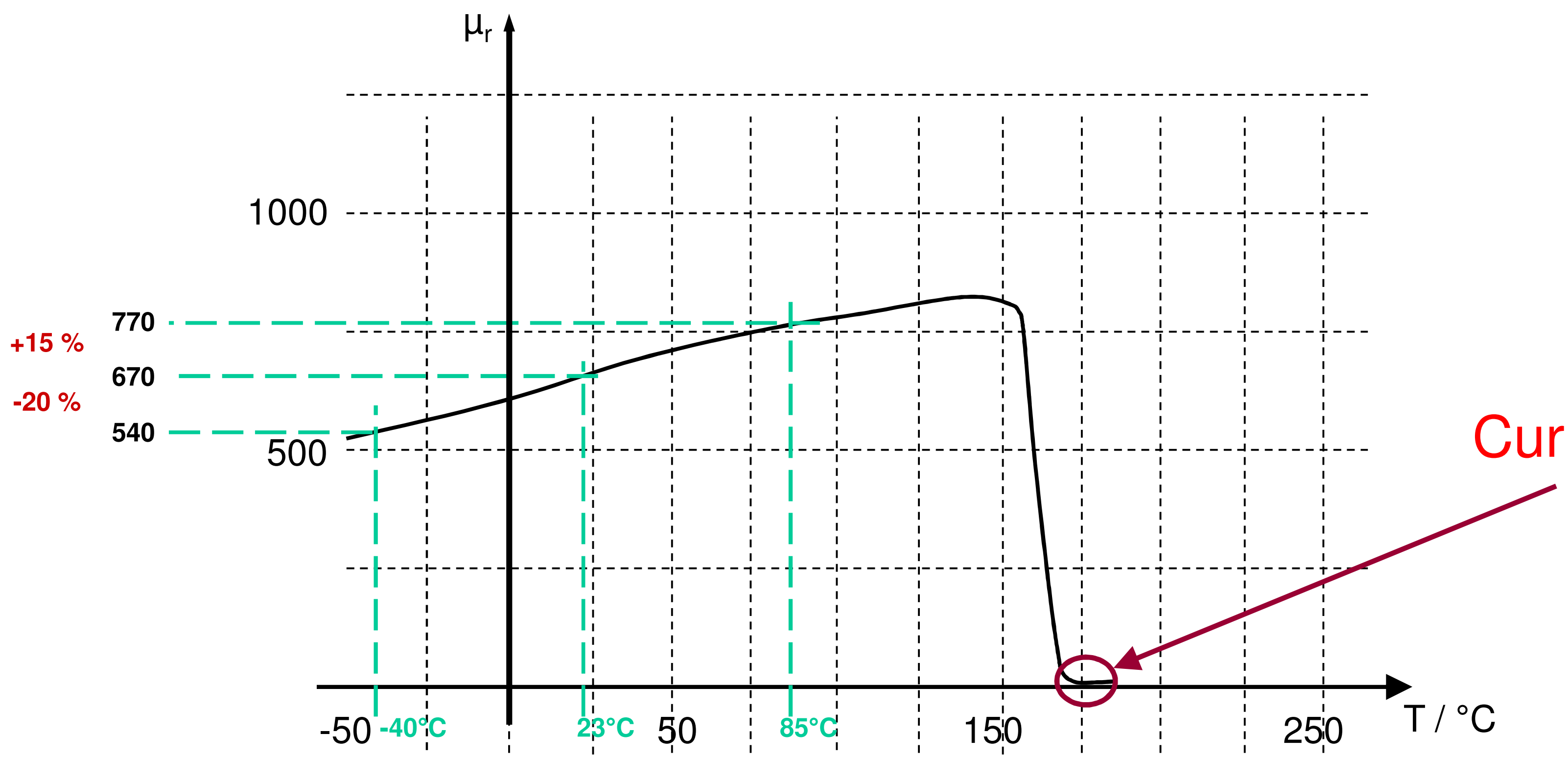
NiZn



CORE GAP, INDUCTOR IMPEDANCE, TEMPERATURE PERFORMANCE AND SHIELDING

Permeability's dependence on temperature

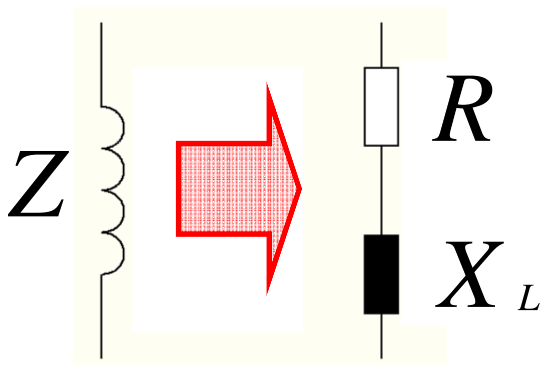
T ↑ ⇝ thermal motion ↑ ⇝ degree of order ↓ ⇝ Alignment of elementary magnets ⇩



μ_r = ?1

Complex Permeability

Equivalent Circuit diagram



$$Z = \sqrt{R^2 + X_L^2}$$

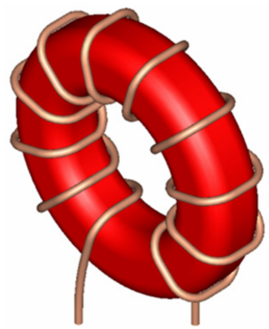
XL is called the reactance (a measure of storing ability)

R is called the resistance (a measure of dissipating ability)

XL is purlely inductive and hence stores and releases energy without any loss

R is purely lossy and hence it dissipates energy

Permeability – complex permeability



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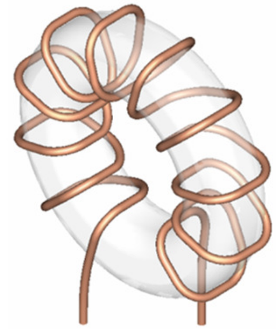
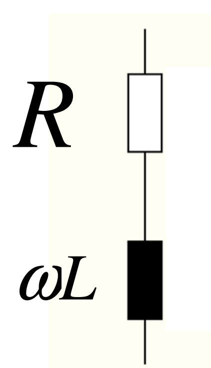


●

Impedance of winding on with core material = **Impedance of winding w/o core material** ● **core material**

$$\underline{Z} = j\omega L_0 \qquad (\mu' - j\mu'')$$



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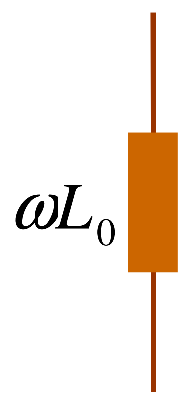

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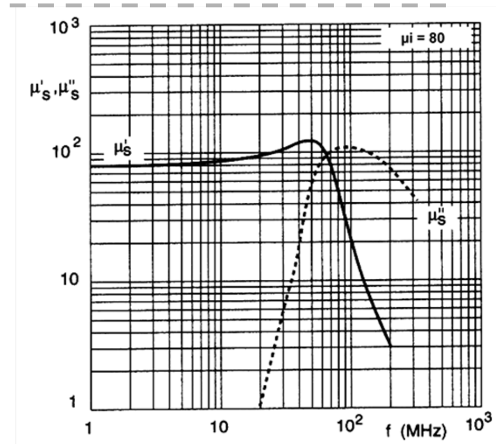


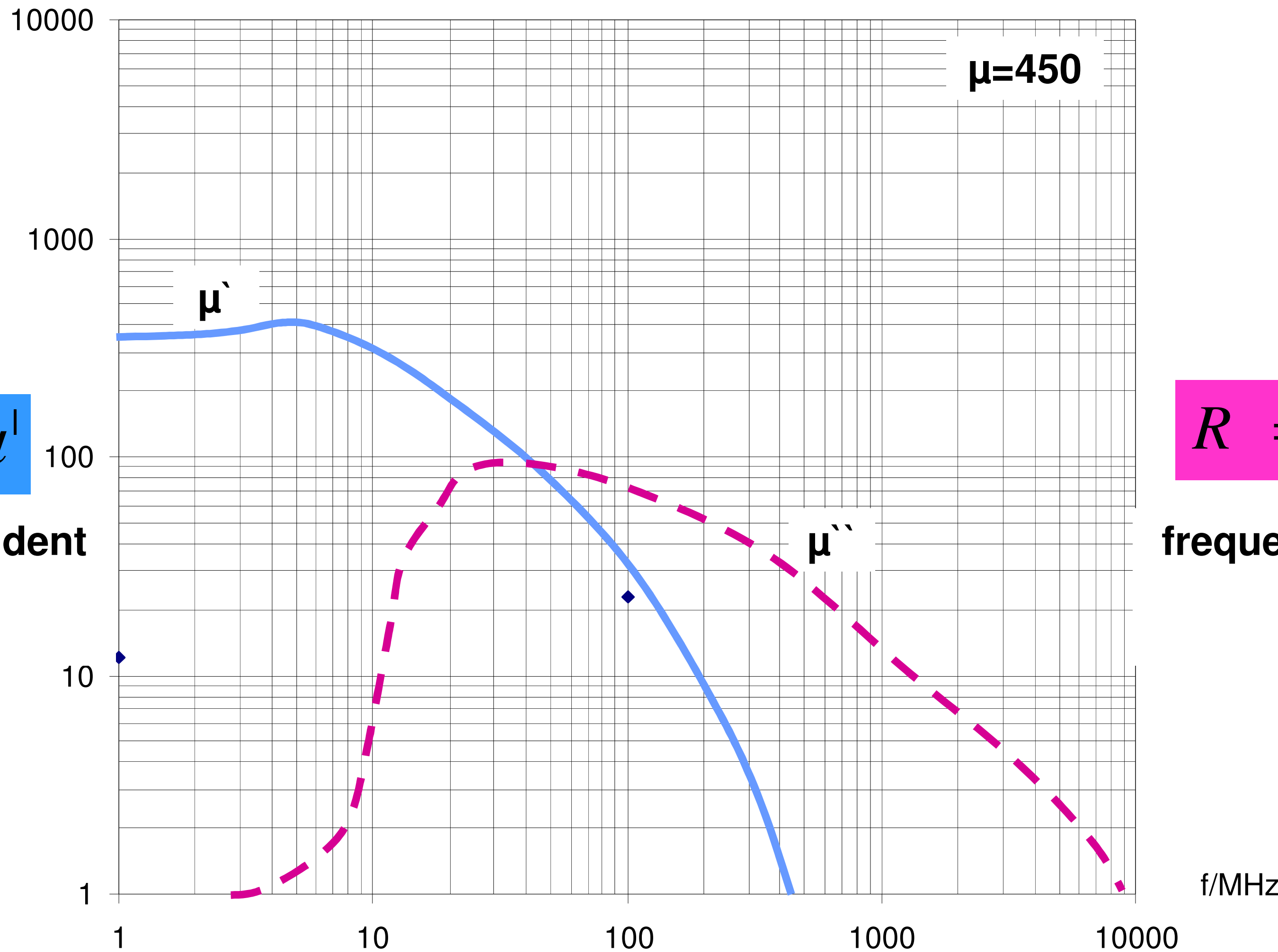
Permeability – complex permeability

$$\underline{Z} = j\omega L_0 \left(\mu' - j\mu''\right) = R + jX$$

$$X_L = j\omega L_0 \mu'$$

frequency dependent inductive part

(Energy storage)



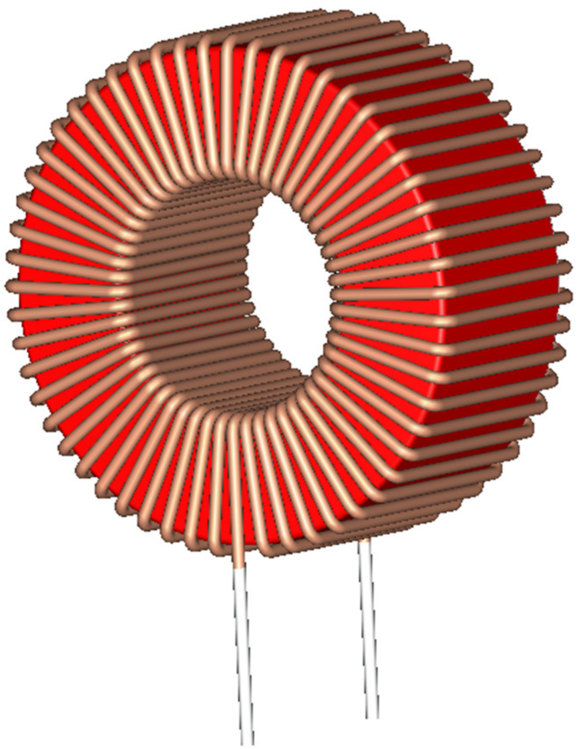
$$R = \omega L_0 \mu''$$

frequency dependent core loses

(Eddy current losses)

Inductance and Core Material Geometry

Toroidal Inductor



$$L = \frac{(\mu_0 * \mu_r * A_{eff} * N^2)}{l_{eff}}$$

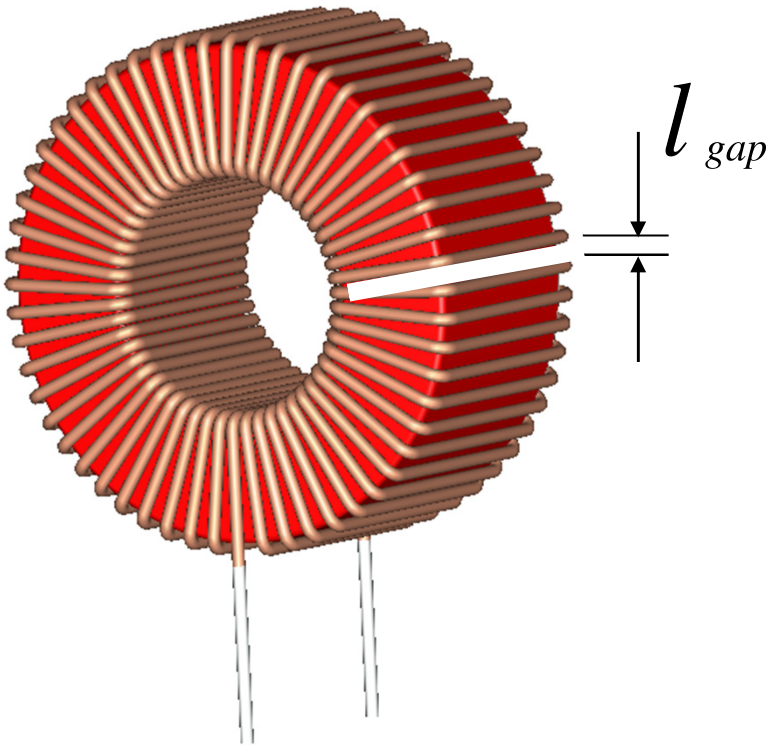
$$\mu_0 = 4 \cdot \pi \cdot 10^{-7}$$

μ_r = relative permeability
N = No. of turns
A_{eff} = effective magnetic area
l_{eff} = effective magnetic length

Inductance and Core Material Geometry

Toroidal Inductor with a gap

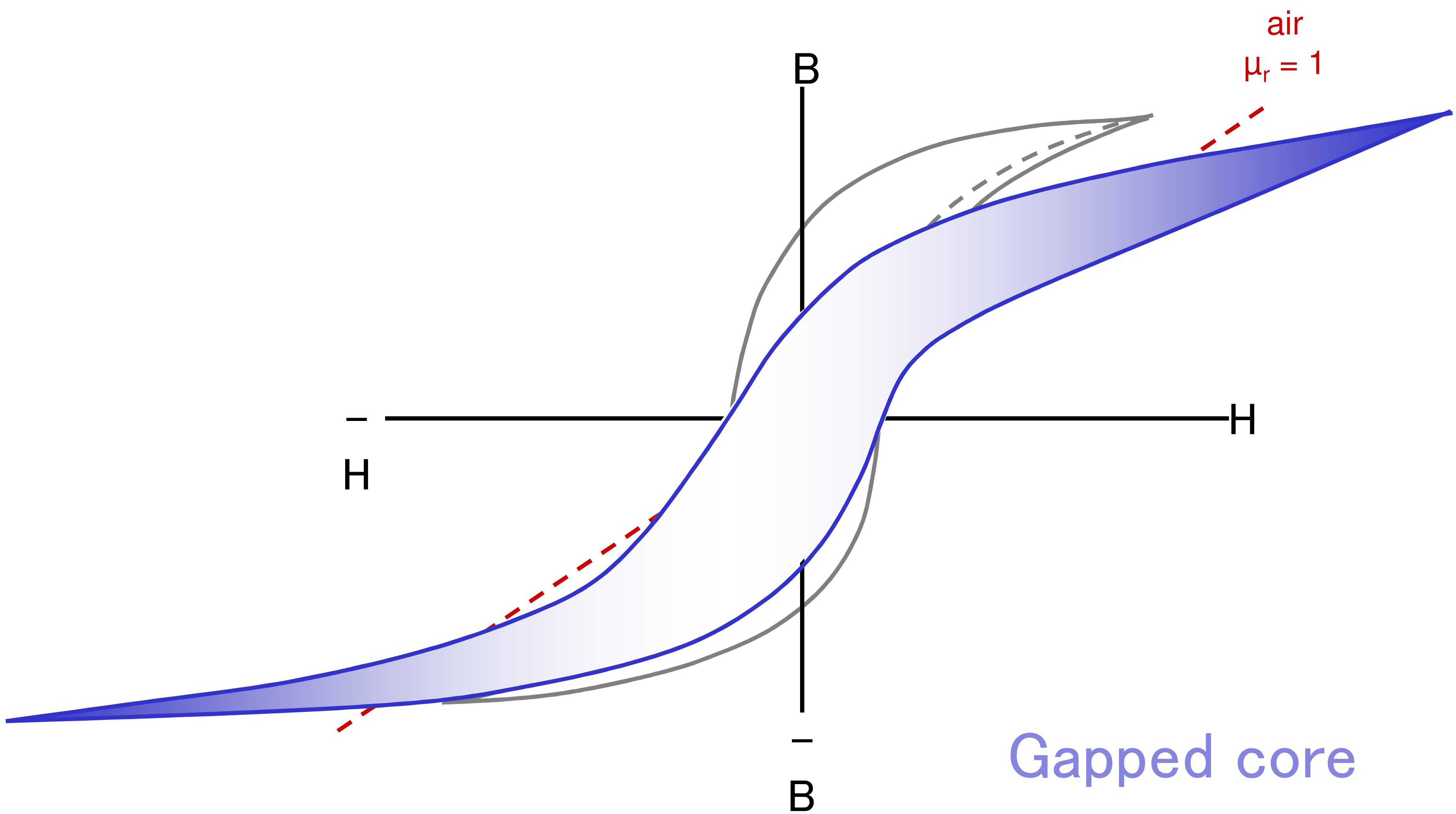
Adding an air gap will increase the effective magnetic length



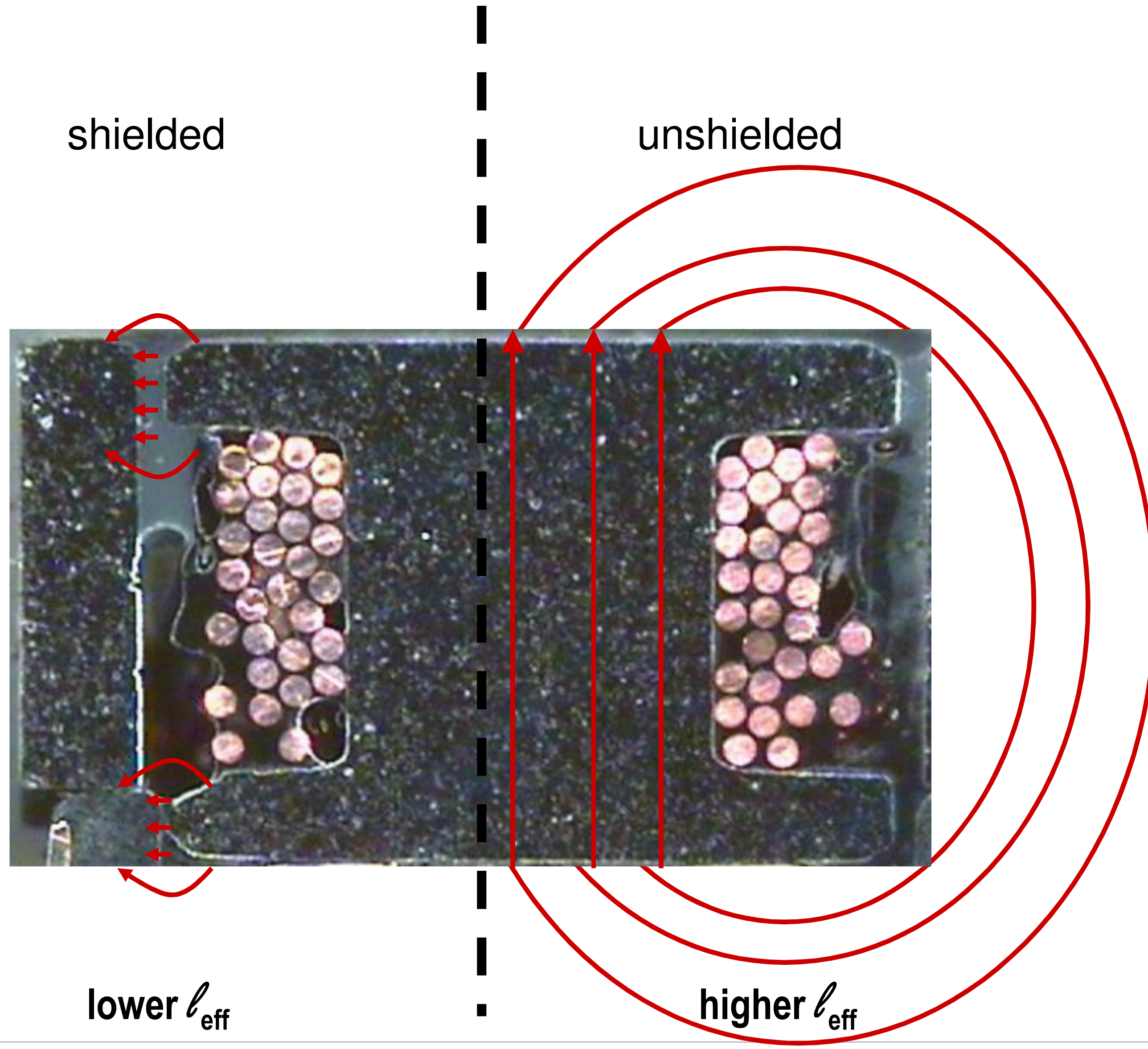
$$L = \frac{(\mu_0 * \mu_r * A_{eff} * N^2)}{l_{eff}}$$

$$l'_{eff} \sim l_{eff} + l_{gap}\,\mu_r$$

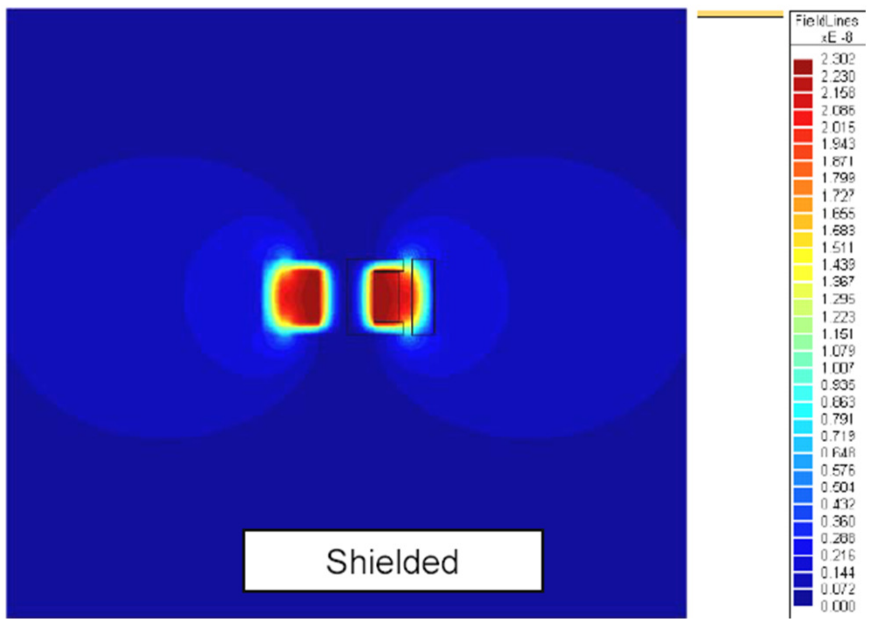
Un-gapped Cores Vs. Gapped cores

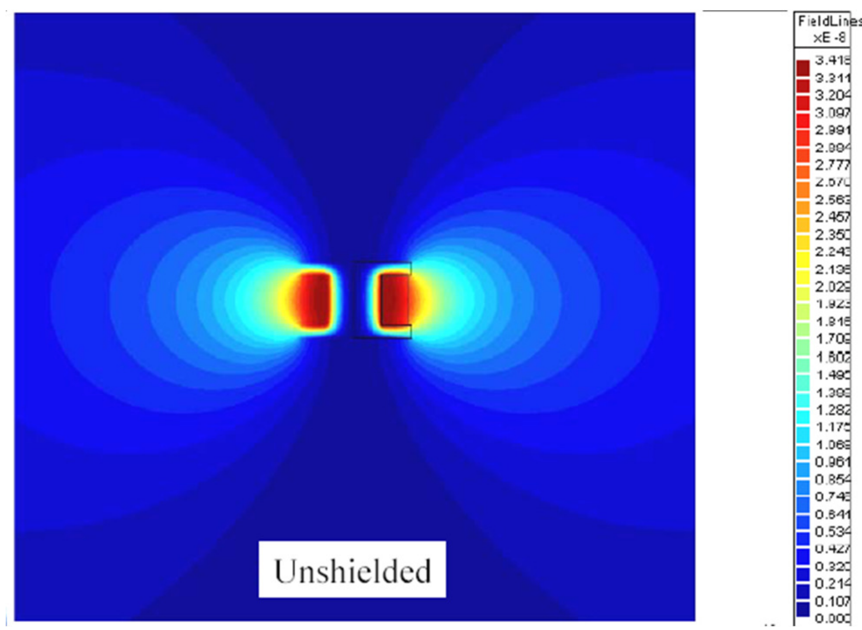


Shielded Vs. Unshielded

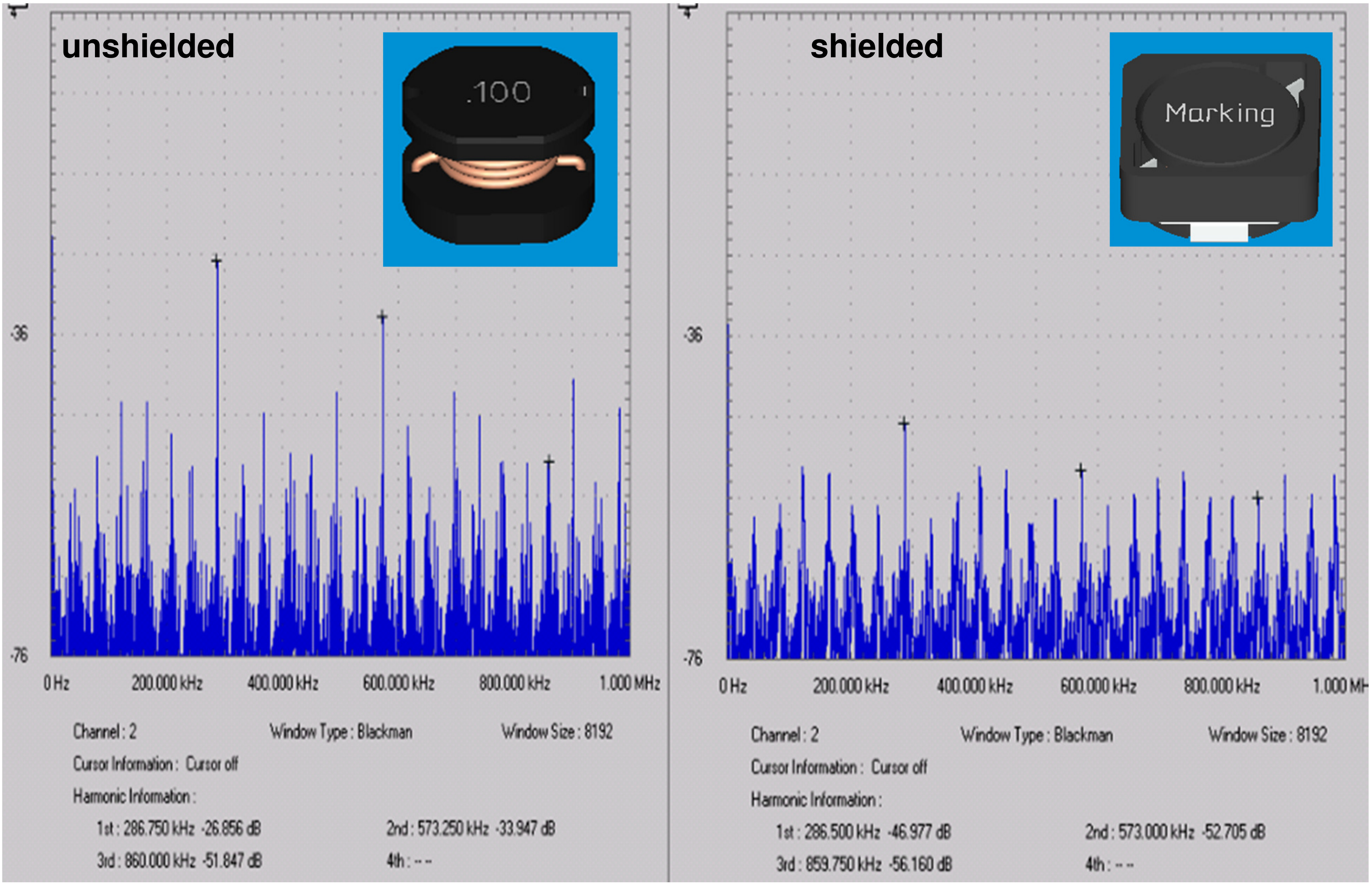


Stray field - Shielded vs. Unshielded

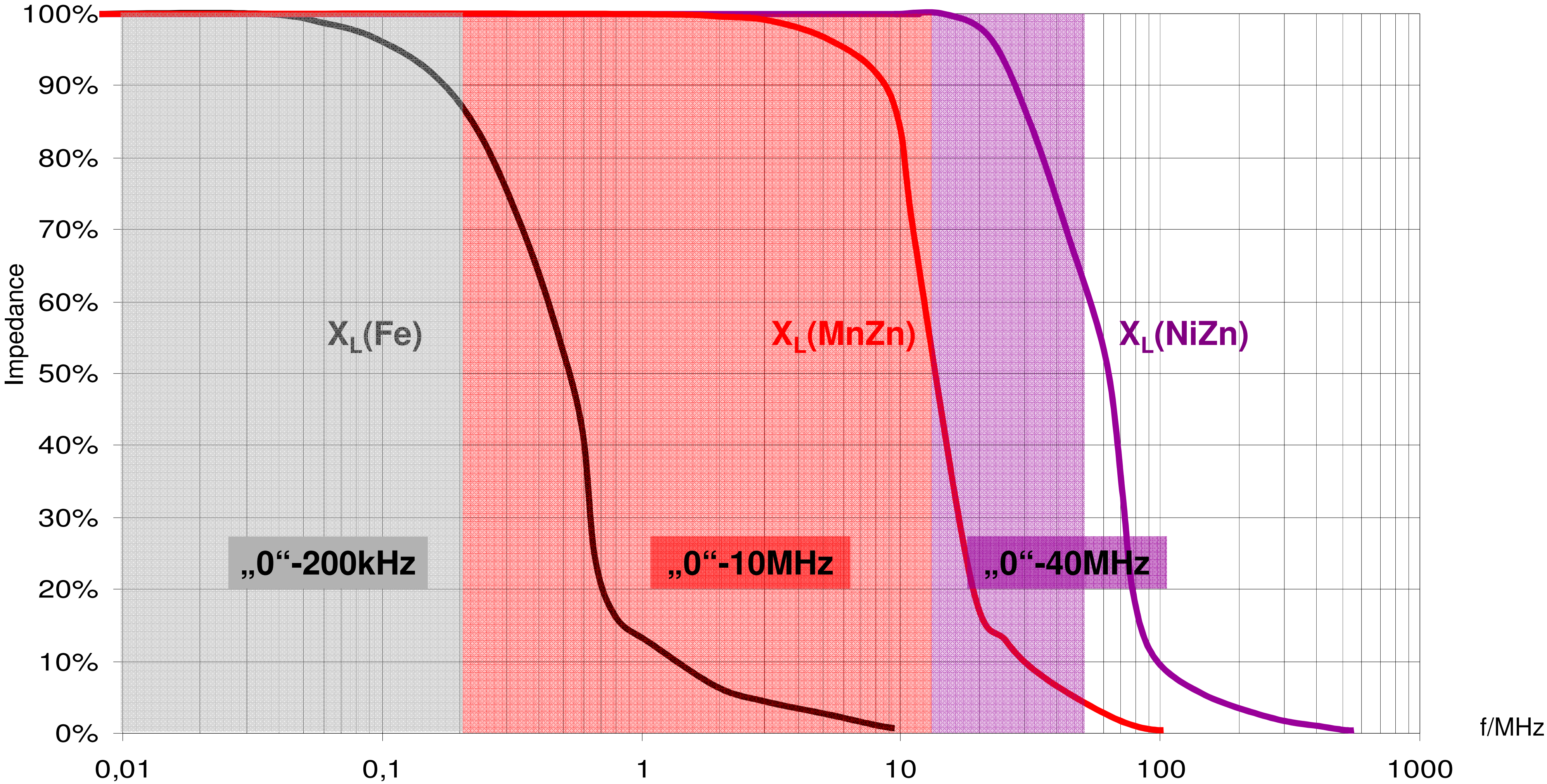




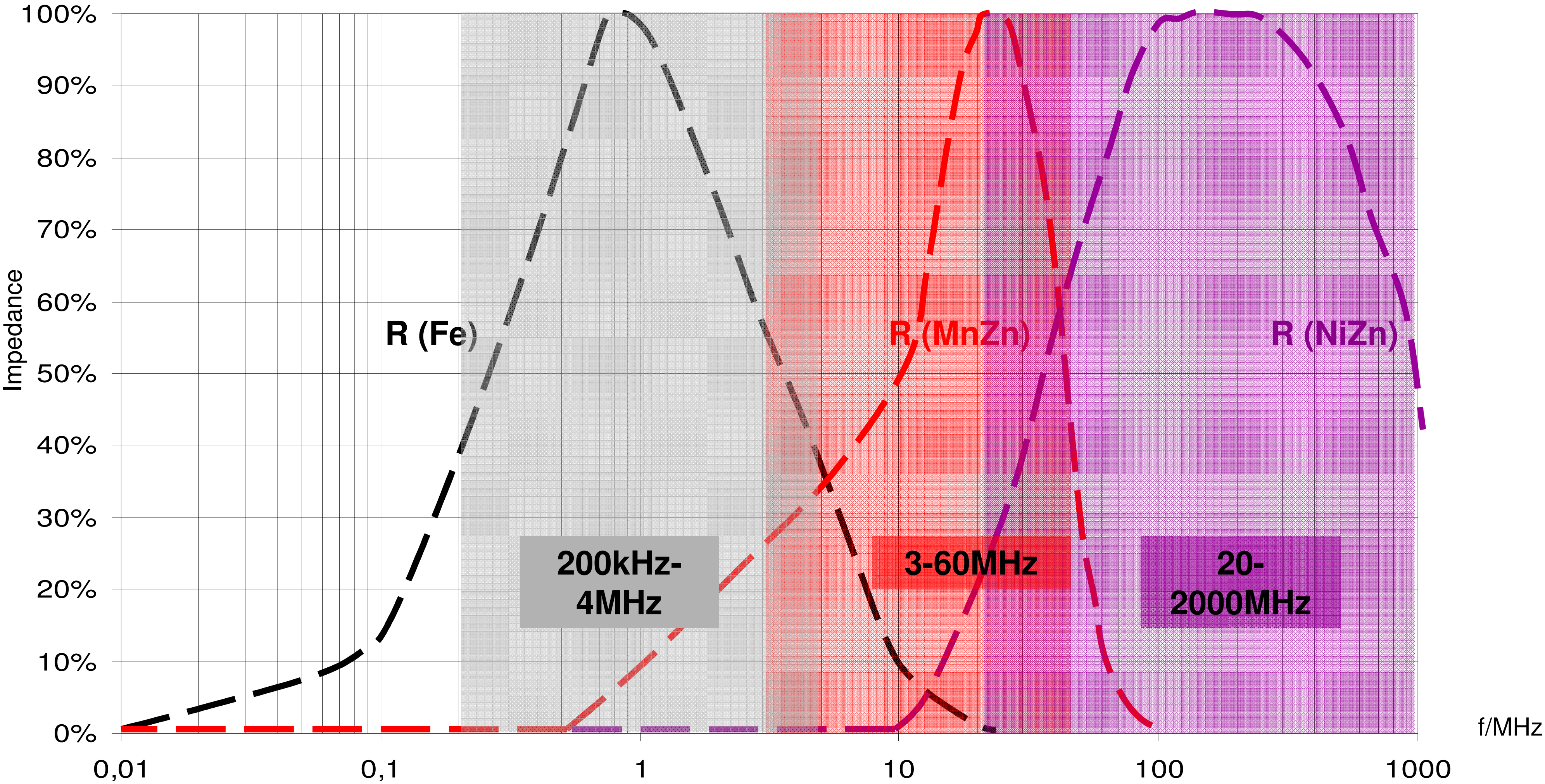
stray field - shielded vs. unshielded



Applications (Inductors for Storage)



Applications (Inductors for Filtering)

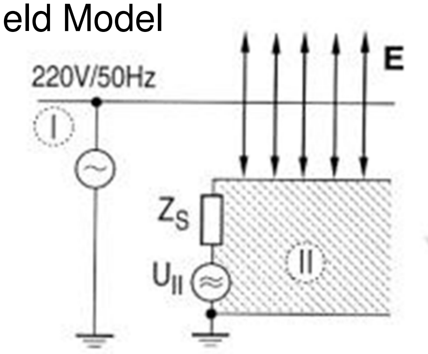


28

Types of Noise Coupling Mechanisms

Capacitive Coupling

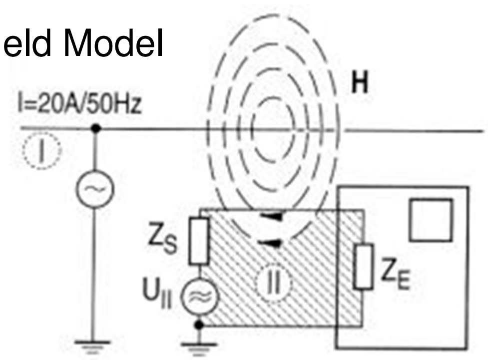
Field Model



Evident in cases where components or traces are at distance of $^1/_{10}$ λ (wavelength) of the **signal frequency**

Inductive Coupling

Field Model



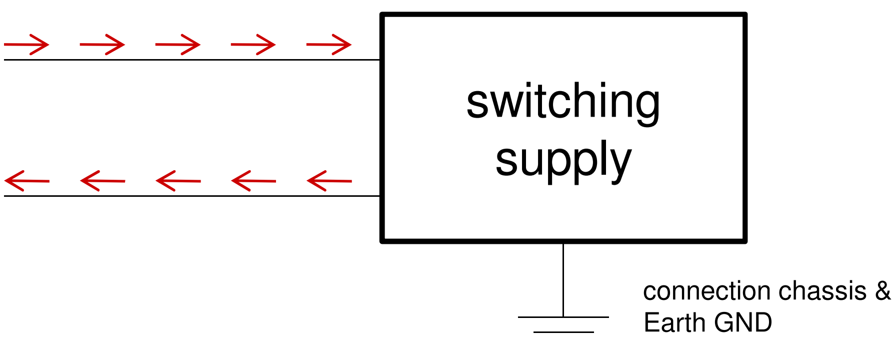
Evident in cases where components or traces are at a distance of ¼ λ (wavelength) of the **noise signal**

COMMON MODE CHOKES

Types of Noise Signals

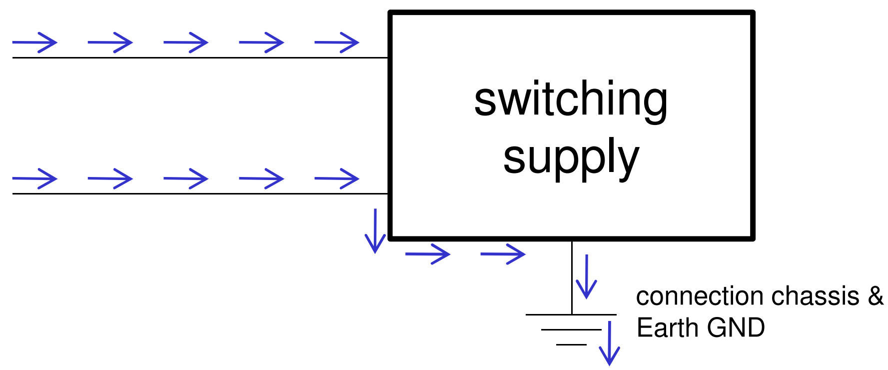
Differential–Mode signal

- Noise flows into one line and exits through another
- Independent from GND



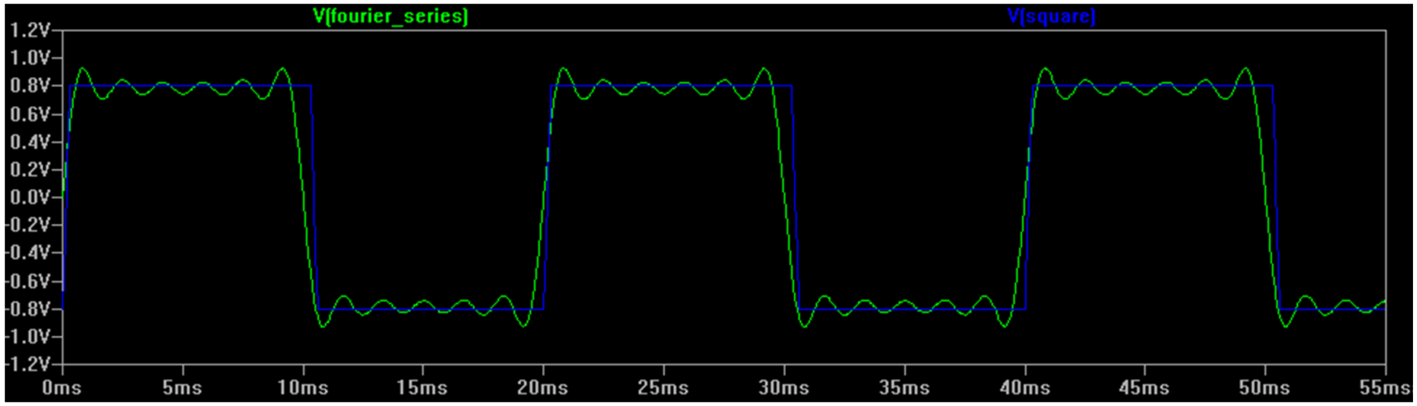
Common–Mode signal

- Noise flows along both lines in the same direction
- returns by some parasitics path through system GND



Common mode choke - advantages

time based



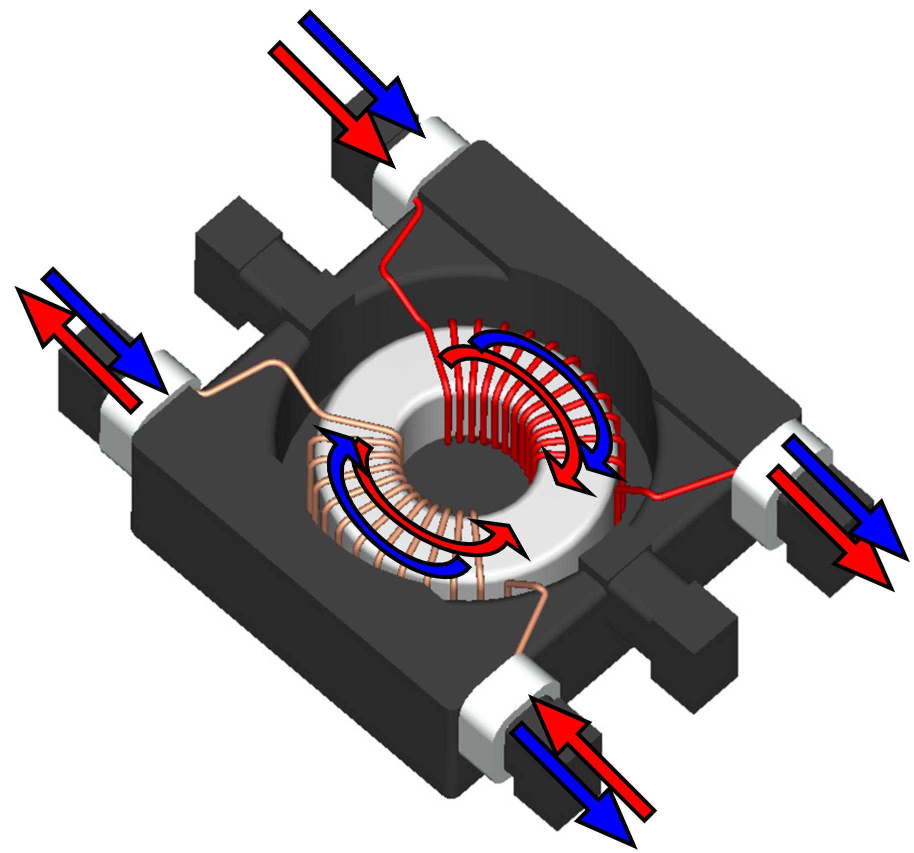
frequency based

Common Mode Filter

WÜRTH ELEKTRONIK

Reduction of noise

- From device to environment
- From environment to device



Conclusion:

- “Almost” no influencing of the signal

→ Differential mode

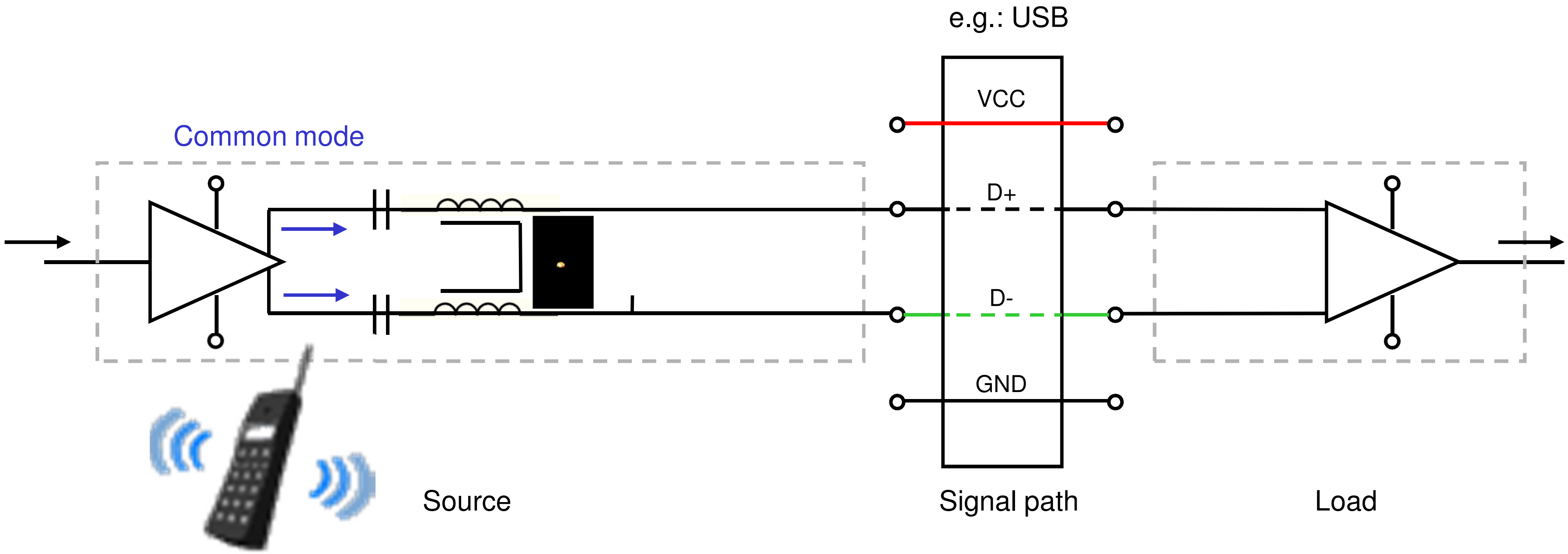
- High attenuation of noise

→ Common mode

33

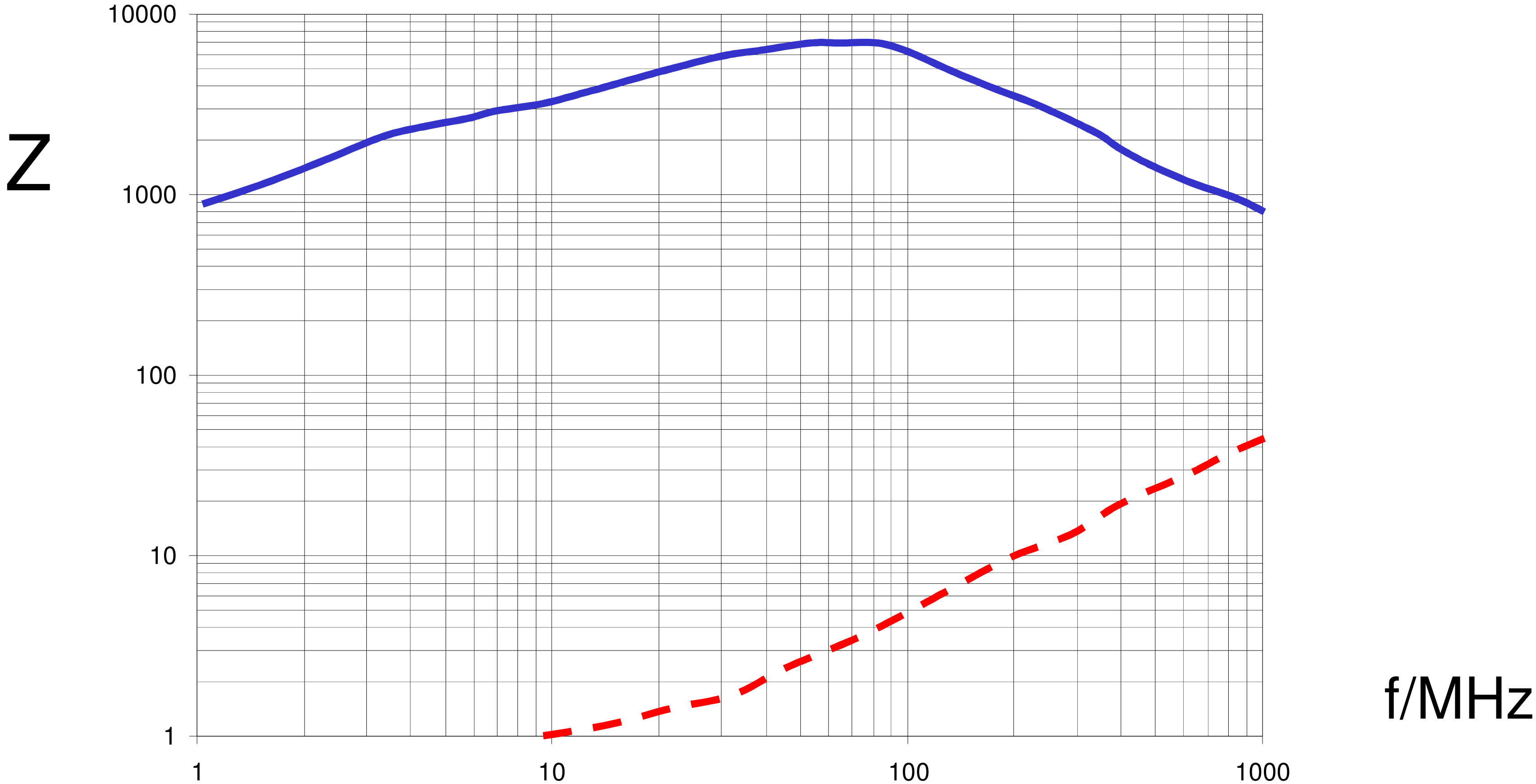
Common Mode Filter – Signal theories

Filtering



Common Mode Filter

- The Common Mode Impedance attenuates just the noise



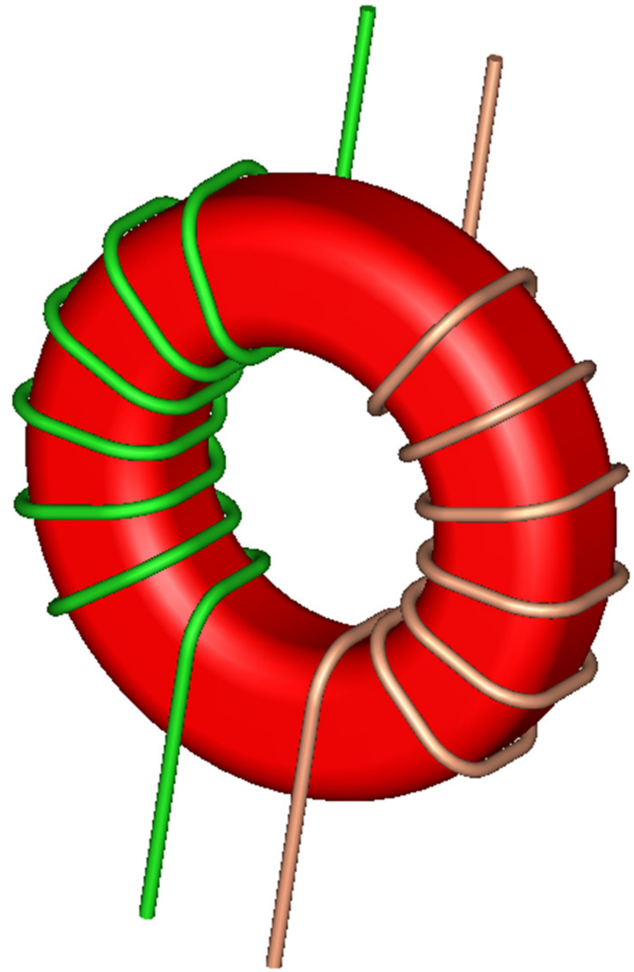
- The Differential mode-Impedance will also attenuate the signal

35

Common Mode Choke Construction

bifilar

sectional

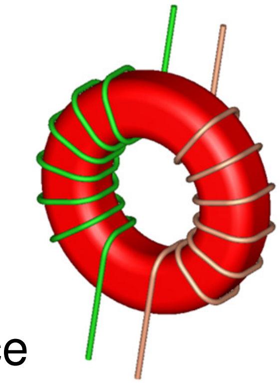


Common mode choke - construction

Bifilar

- Less differential impedance
- High capacitive coupling
- Less leakage inductance

Sectional



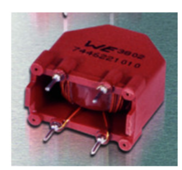
- Low capacitive coupling
- High leakage inductance
- High differential impedance

- Data lines
  → USB, Fire-wire, CAN, etc.
- Power supply
- Measuring lines
- Sensor lines

- Power supply input /output filter
  → CMC for mains power
- High voltage application
- Measuring lines
- Switching power supply decoupling

- WE-CNSW

- WE-SLM



- WE-LF
- WE-SLx-Series

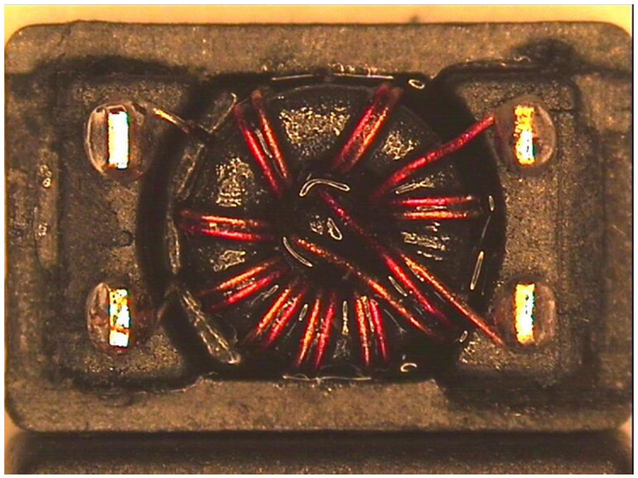
- WE-CMB
- WE-VB / VB2

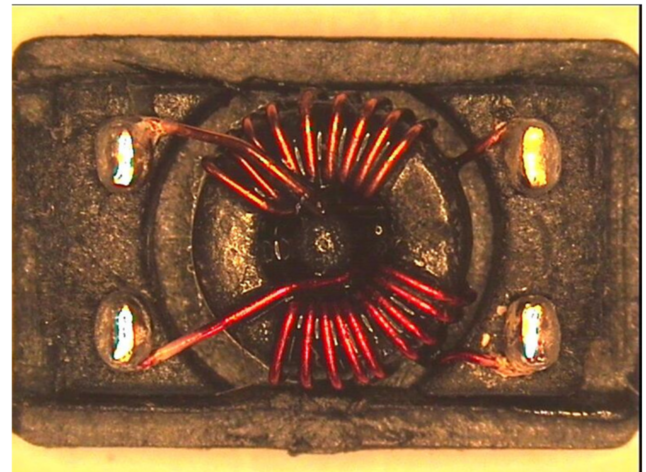
Common mode choke - construction

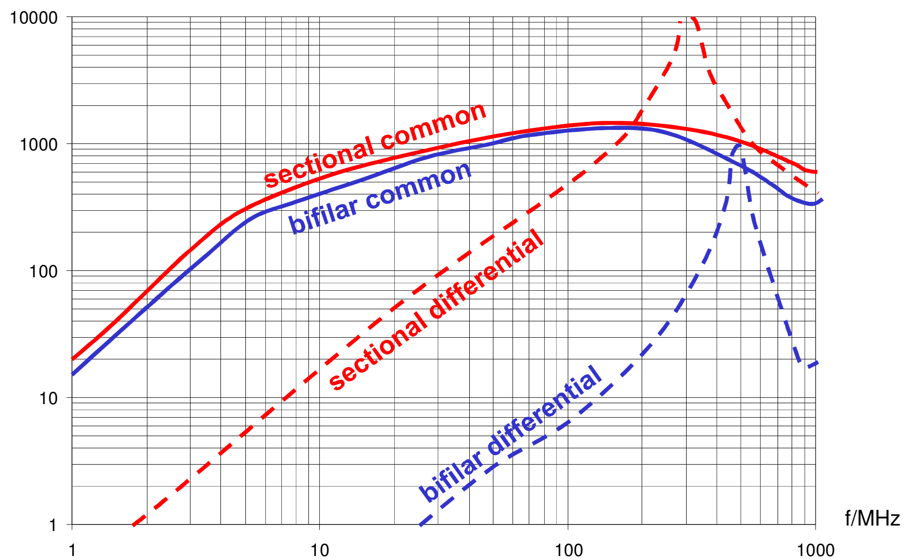
WÜRTH ELEKTRONIK

bifilar winding

sectional winding





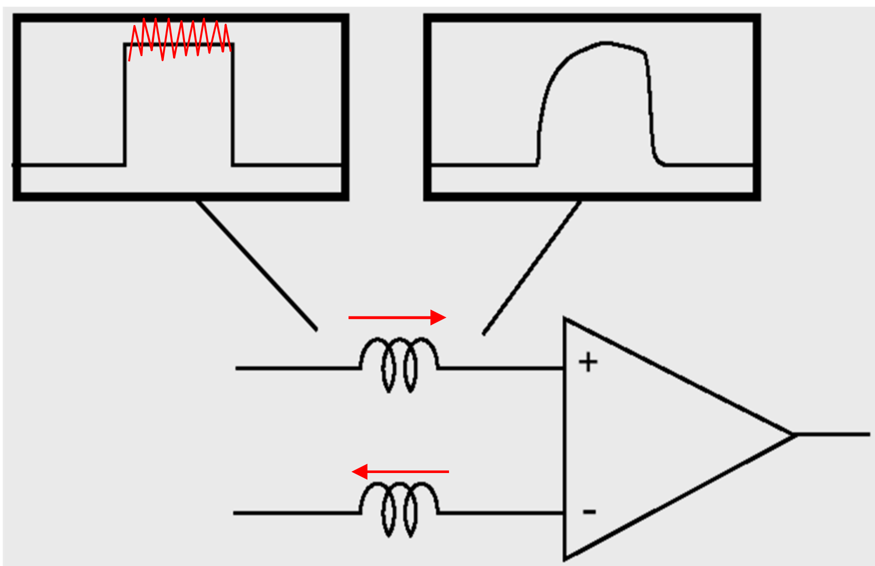


Common mode choke - advantages

Filter with two inductors

Filter input

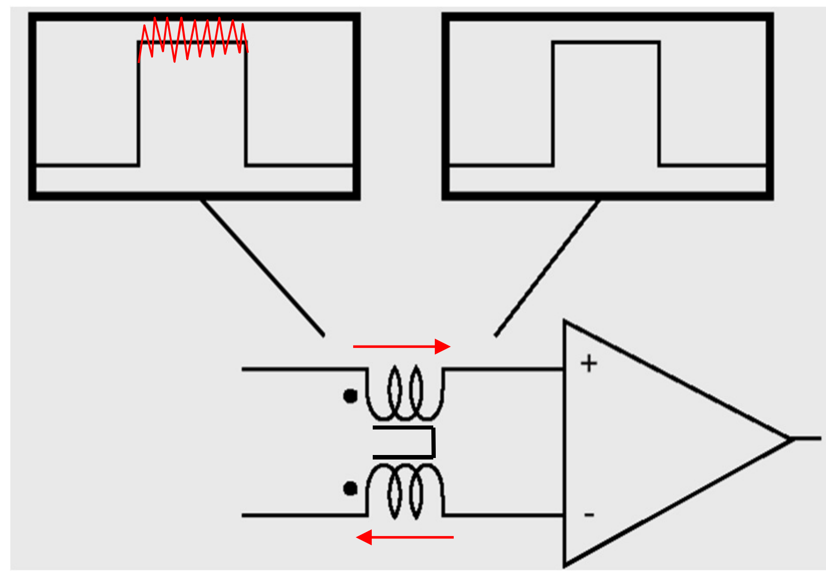
Filter output



Filter with CMC

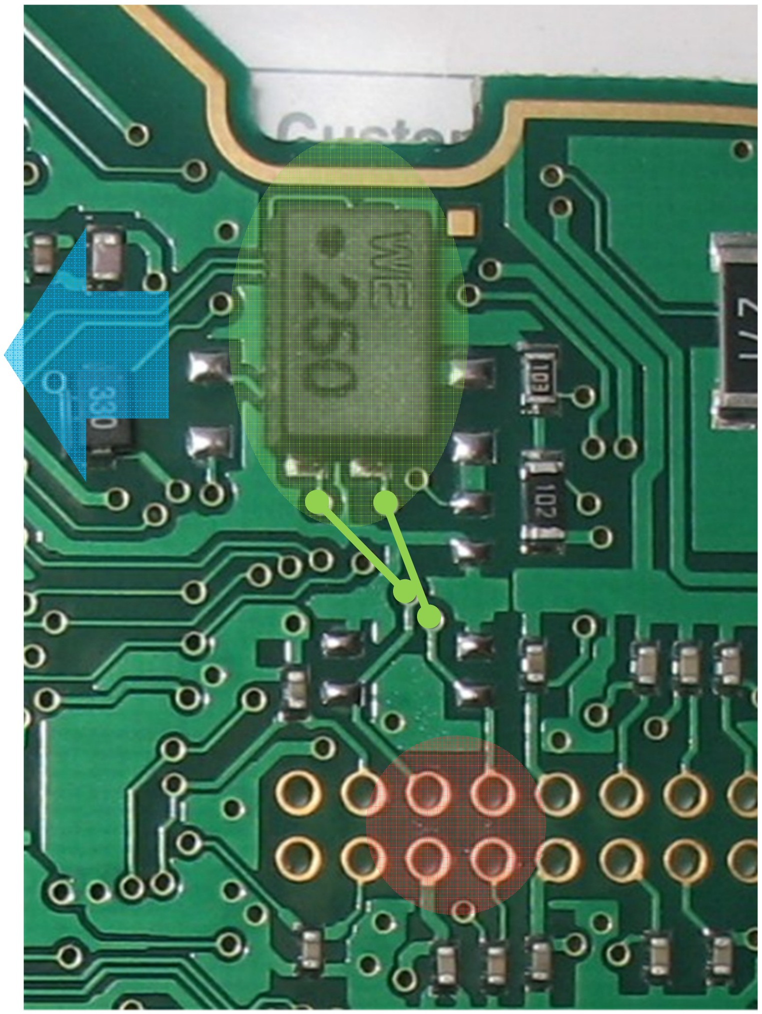
Filter input

Filter output



- no signal distortion – means signal will be not affected

Common mode choke - advantages



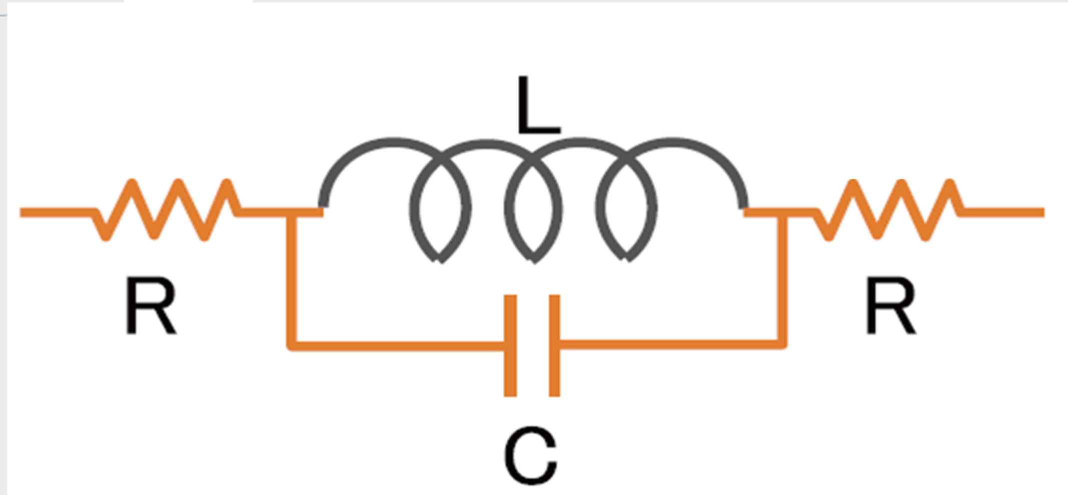
Digital logic device

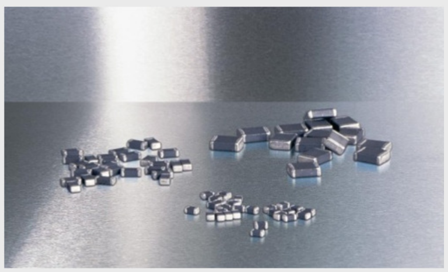
Common Mode Choke

Interconnection → Cable/Connector

CHIP BEAD FERRITES

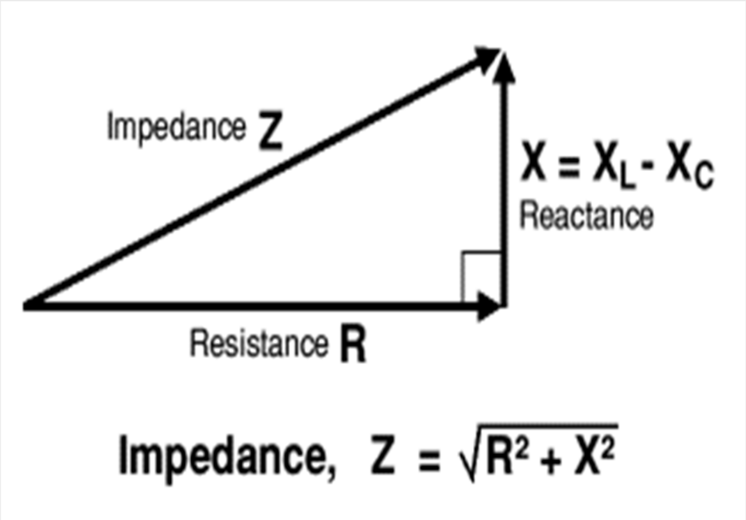
Chip Bead Ferrites

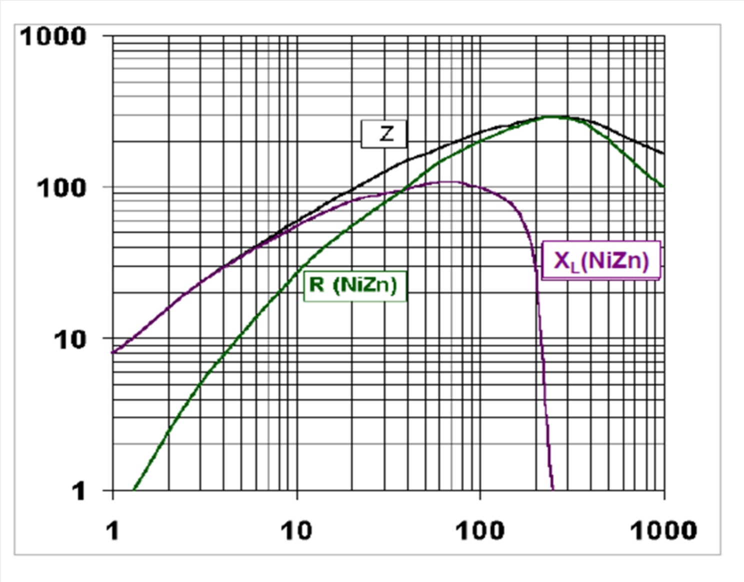




- Inductor
  - Used to filter unwanted noise
  - Supply voltage lines, ground planes, and data signals
- Frequency Dependant
  - Also know as a frequency dependent resistor

Chip Bead Ferrites Impedance



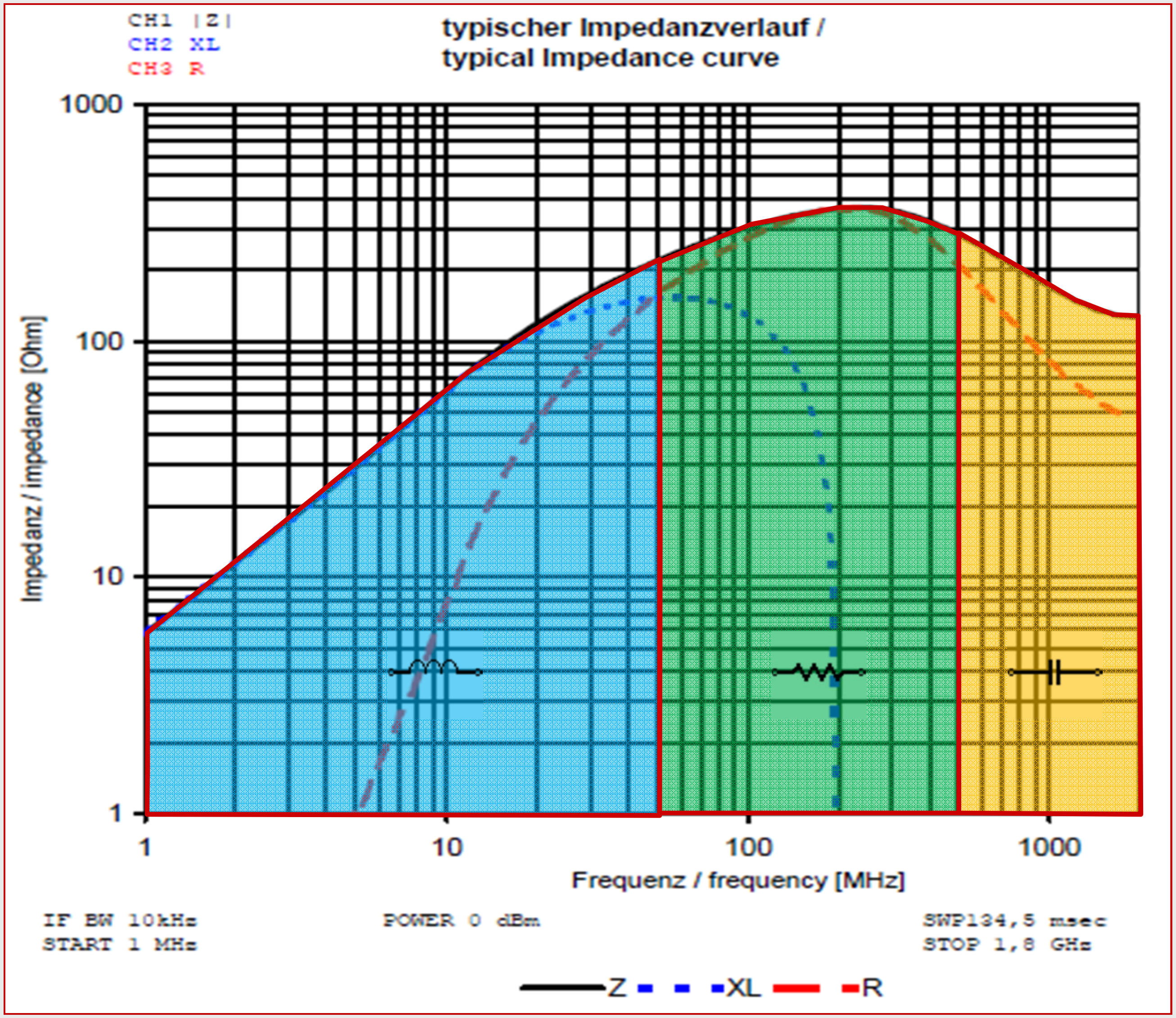


- AC resistance equivalent
  - Impedance can be split into two parts
    - Resistance R (Constant regardless of frequency)
    - Reactance X (Varies with frequency)

Chip Bead Ferrites

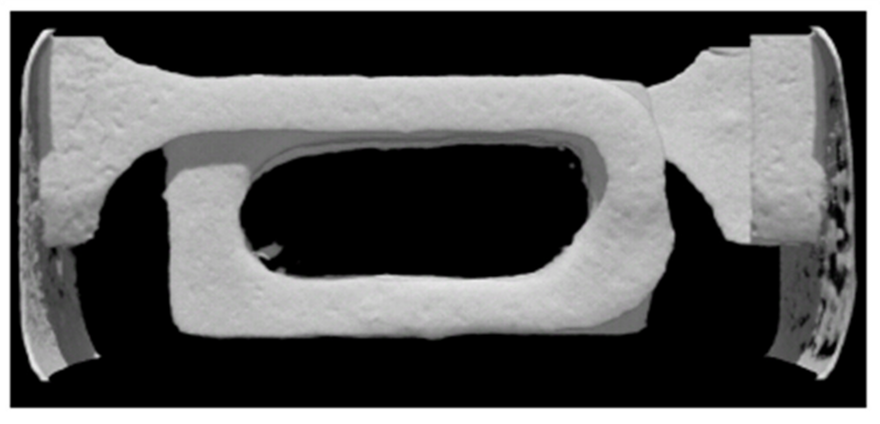
- Resistive
  - Impedes the noise energy and absorbs it
- Inductive
  - Energy storage
- Capacitive
  - Passes AC, blocks DC

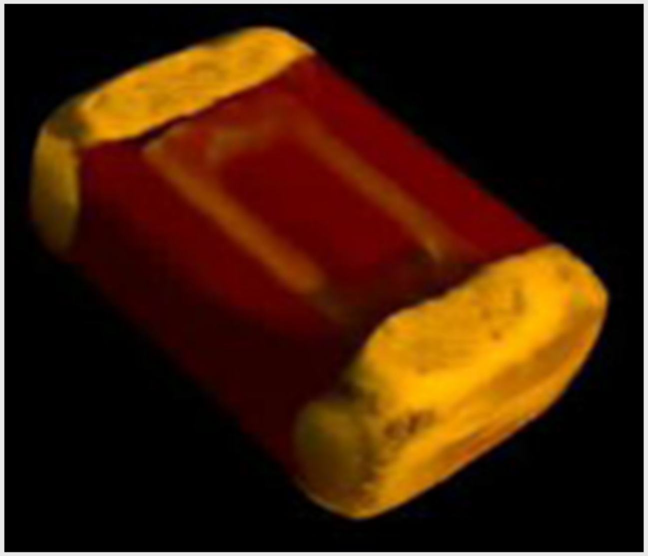
SRF XL=XC



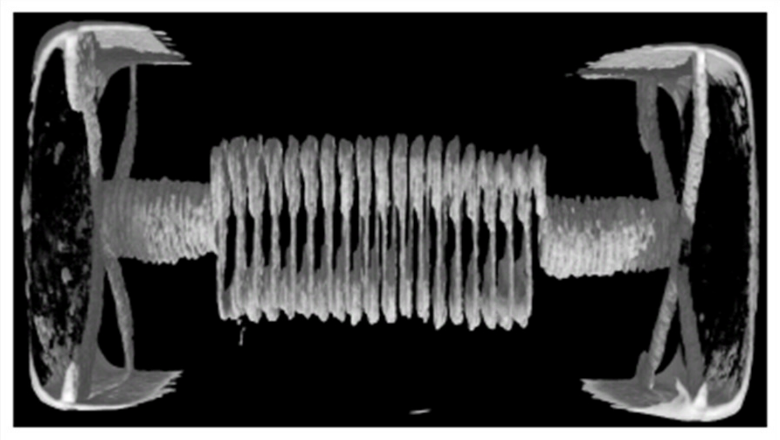
Chip Bead Ferrites

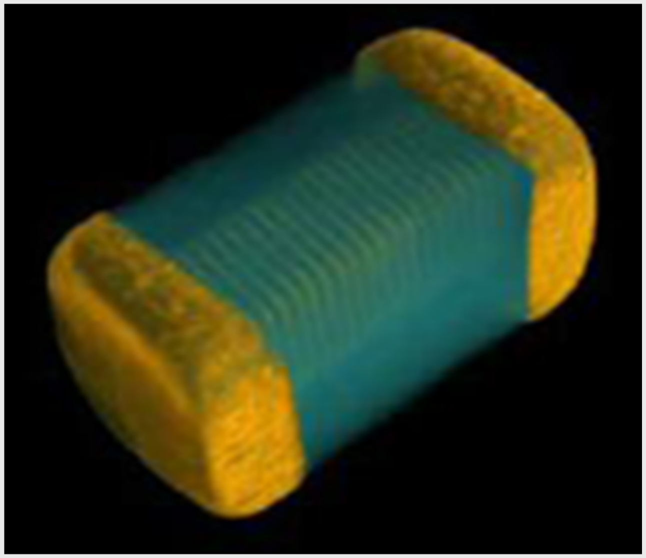
High Current



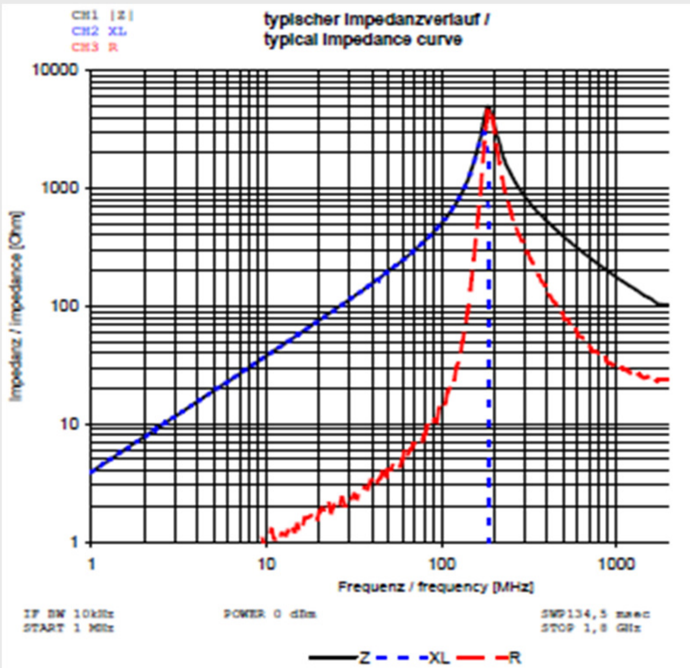


High Frequency



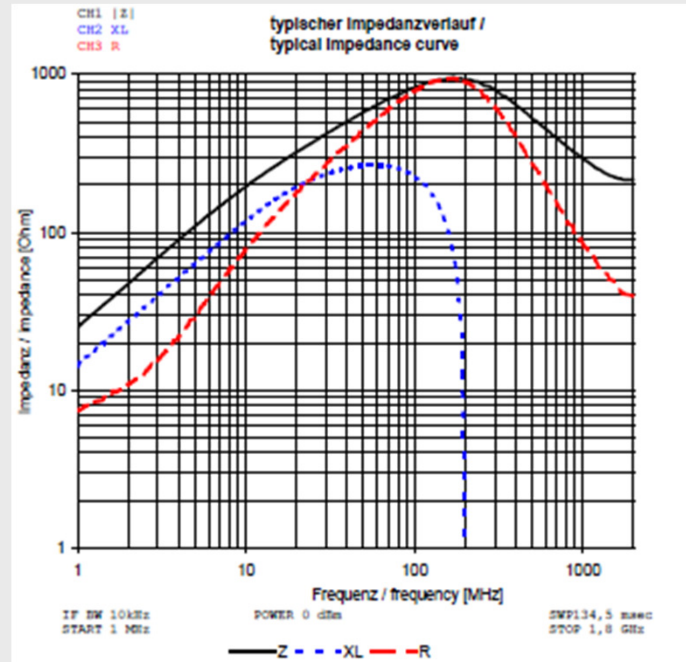


Chip Bead Ferrites



High speed

- Lower impedance in lower frequency
- Low attenuation for fast signals
- Applications: USB 2.0, IEEE 1394, LVDS

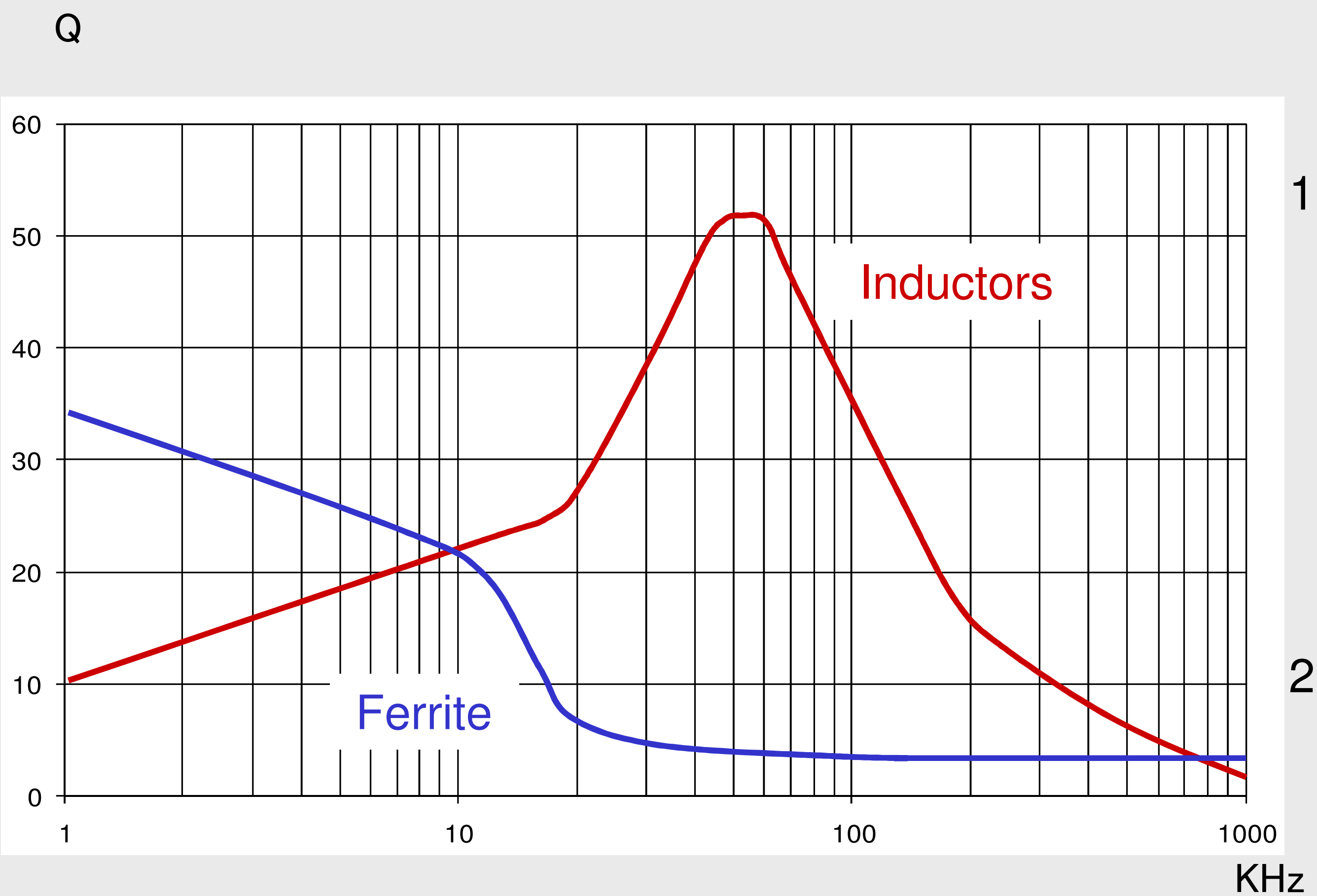


Wide band

- High impedance in low frequency
- Wide band through the entire spectrum
- Applications: DC/DC converters

Q factor Application

$$Q = \frac{X_L}{R}$$

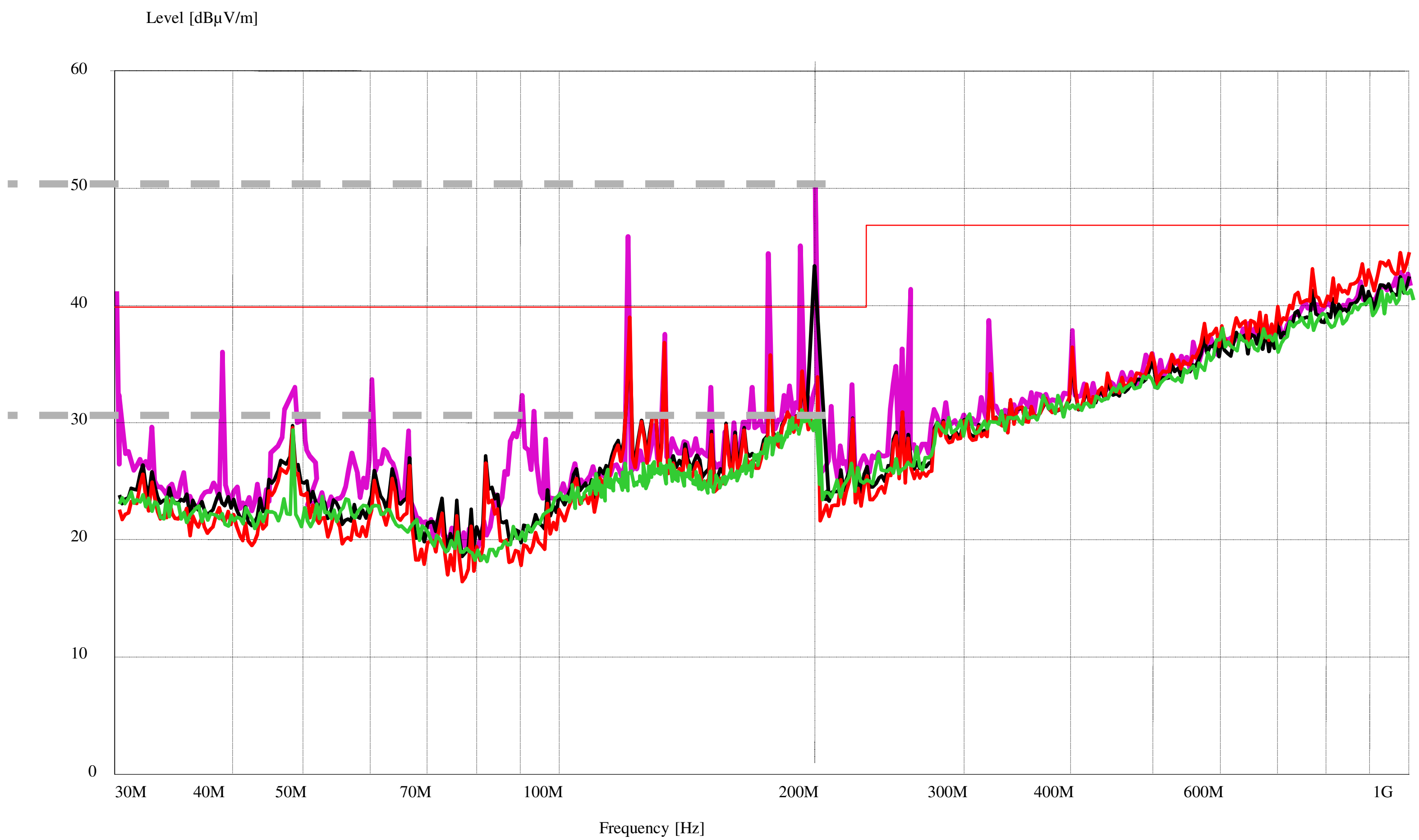


1. Application: **Storage inductor**
    1. **Request: Lowest possible core losses at switching frequency (HIGH Q)**
2. Application: Absorber / Filter
    1. **Request: Highest possible core losses at application frequency (LOW Q)**

Insertion loss - example

- check the results

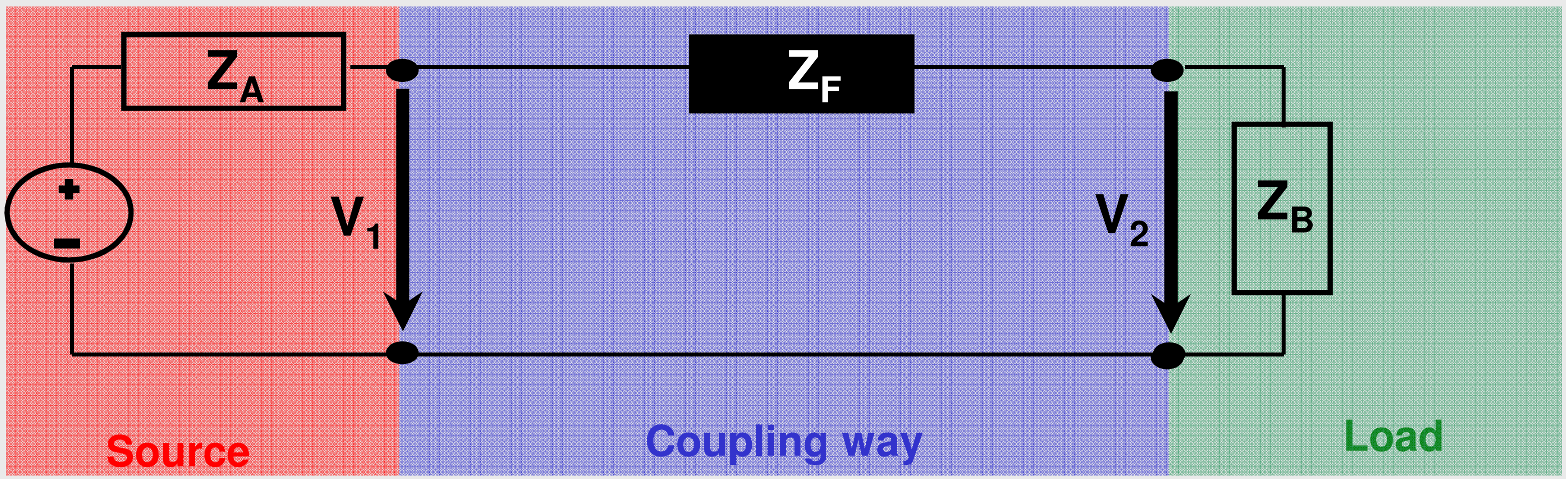
→ measuring the emission and compare the attenuation



Insertion loss calculation

more than you expect

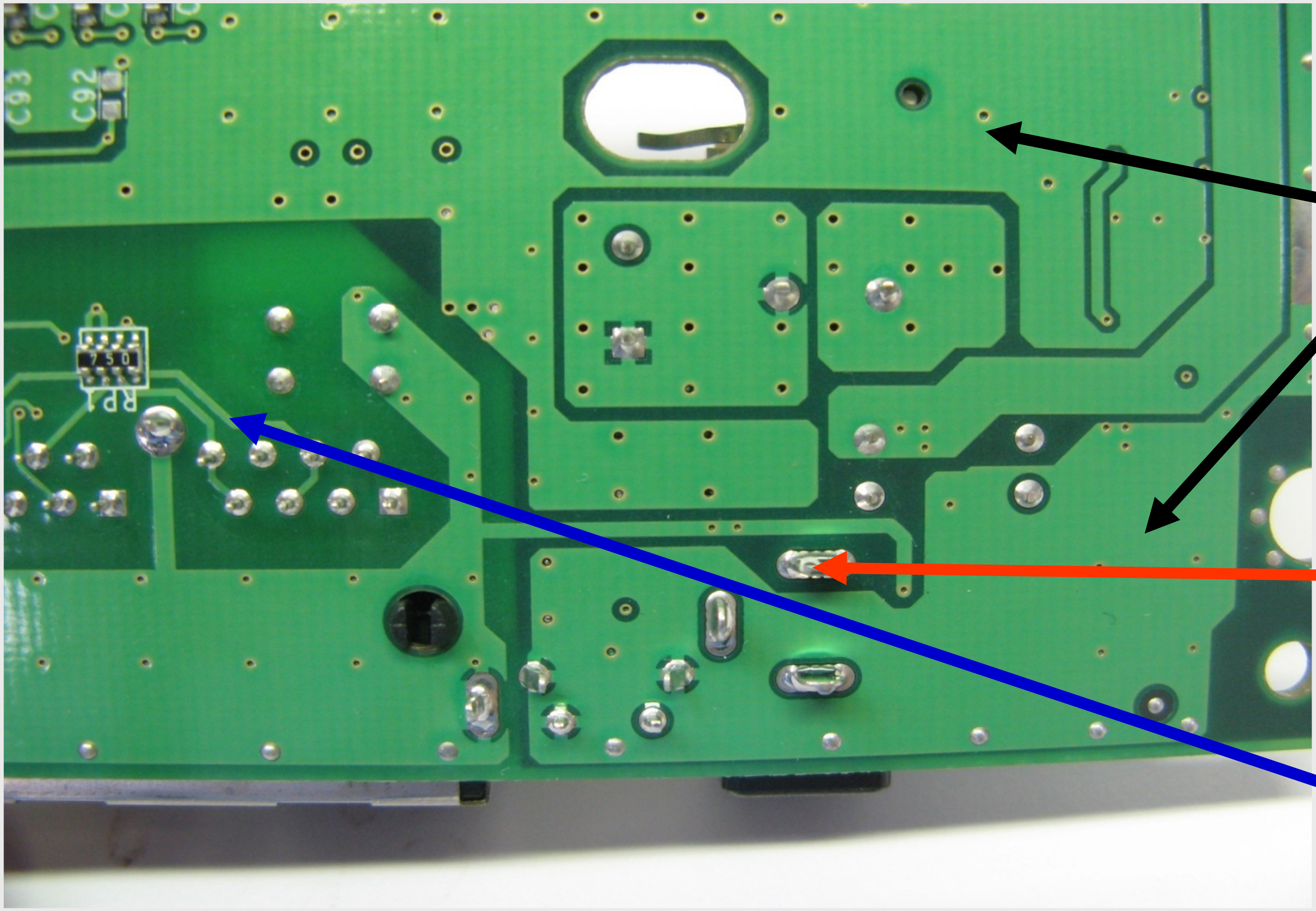
The logarithmic ratio of input power to output power, which, describes the signal attenuation along a defined transmission patch.



- System attenuation $$A = 20 \cdot \log \frac{Z_A + Z_F + Z_B}{Z_A + Z_B} \quad in \quad (dB)$$

- Impedance $$Z_F = \left[10^{\frac{A}{20}} \cdot \left(Z_A + Z_B \right) \right] - \left(Z_A + Z_B \right) \quad in \quad (\Omega)$$

Insertion loss calculation



1 Ω

Ground plane

10 Ω

Supply voltage line

50 Ω - 90 Ω

Data signal lines

Insertion loss calculation

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$$Z_F = \left[10^{\frac{A}{20}} \cdot (Z_A + Z_B)\right] - (Z_A + Z_B)$$

$$Z_F = \left[10^{\frac{12}{20}} \cdot (10_A + 10_B)\right] - (10_A + 10_B)$$

$$Z_F = 59.6\Omega$$

$$A = 20 \log \frac{Z_A + Z_F + Z_B}{Z_A + Z_B}$$

$$A = 20 \log \frac{10_A + 59.6_F + 10_B}{10_A + 10_B}$$

$$A = 20 \log 3.98$$

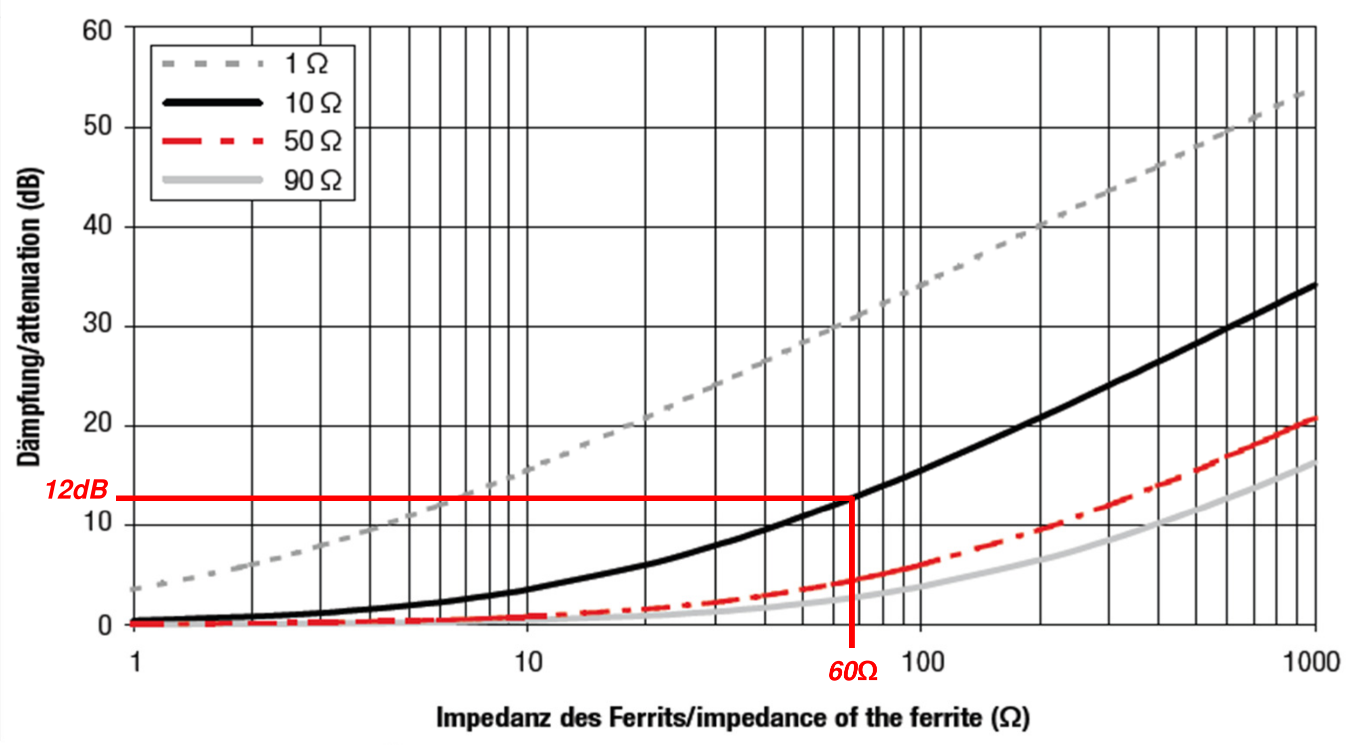
$$A = 11.99\ dB$$

1. **Require 12dB of attenuation at 125 MHz**
2. **Know that it is a power cable**
3. **Power port has 10 Ω impedance**
4. **Result is a impedance of 60 Ω**

Application overview

Assumend practical system impedance	**Application**
1 Ω	GND (Ground Planes)
10 Ω	V_{cc} (Supply Voltage lines)
50 Ω – 90 Ω	Datasignal Lines/Clock/ Video Signal/USB
90 Ω – 150 Ω	Long Datasignal Lines

Insertion loss calculation



Application overview

Assumend practical system impedance	Application
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90 Ω – 150 Ω	Long Datasignal Lines

1. Require 12dB of attenuation at 125 MHz
2. Know that it is a power cable
3. Power port has 10 Ω impedance
4. Result is a impedance of 60 Ω

Errors are generally due to wrong system impedance estimation

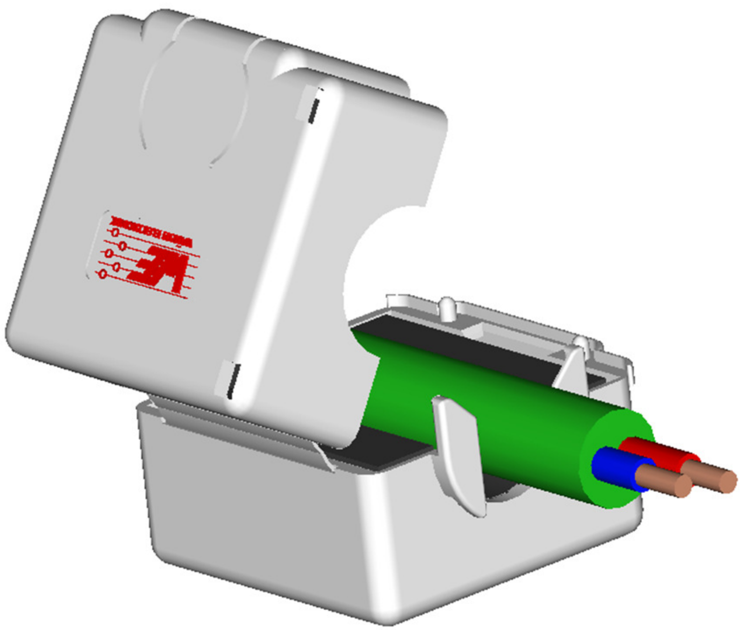
→Too much attenuation. Reduce the impedance of ferrite

→Too little attenuation. Increase the impedance of ferrite

CLAMP-ON FERRITES

Clamp On Ferrites

Comparable Performance to a bifilar winding Common Mode Choke

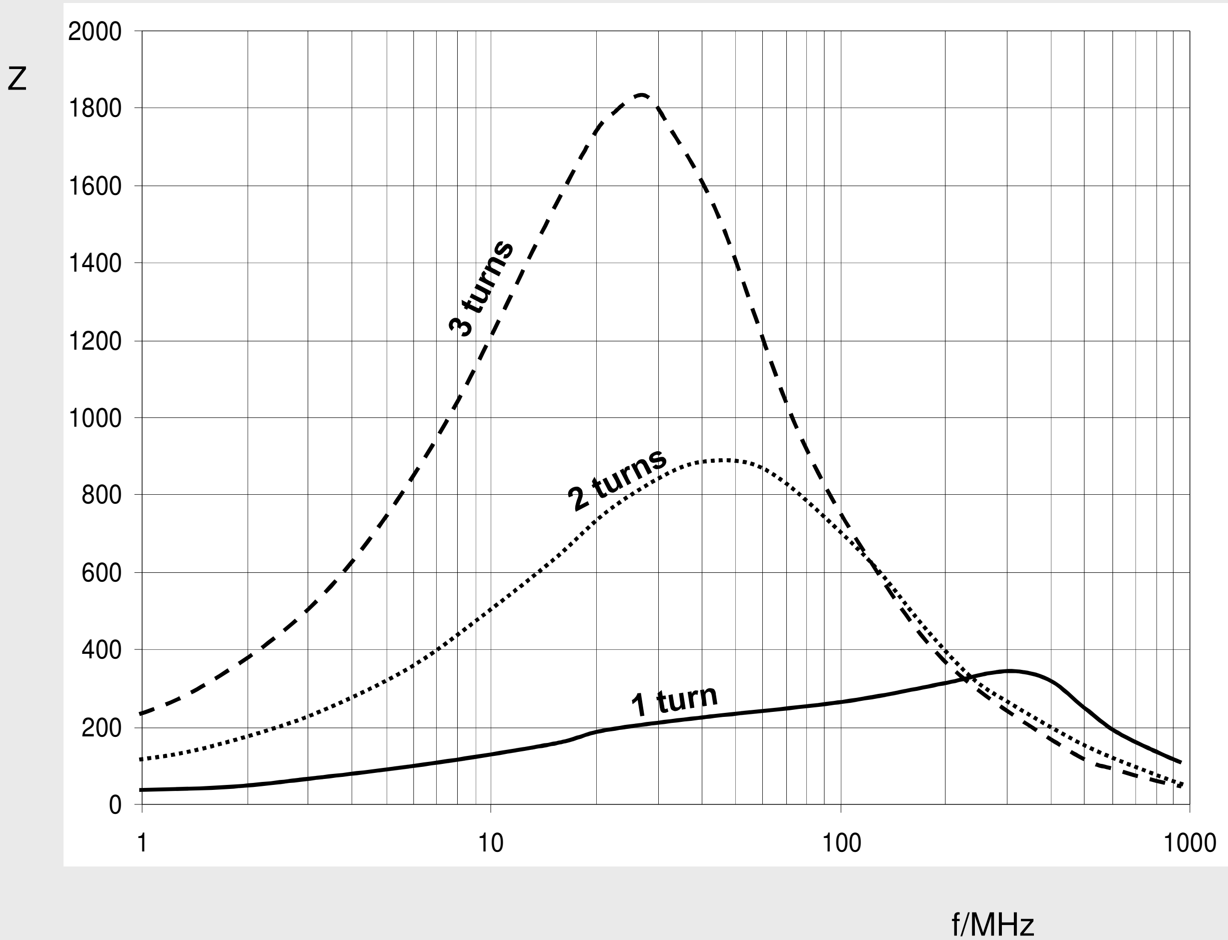


~

- Both will absorb Common Mode interferences
- Clamp on Ferrite is a Common Mode Choke with ONE winding

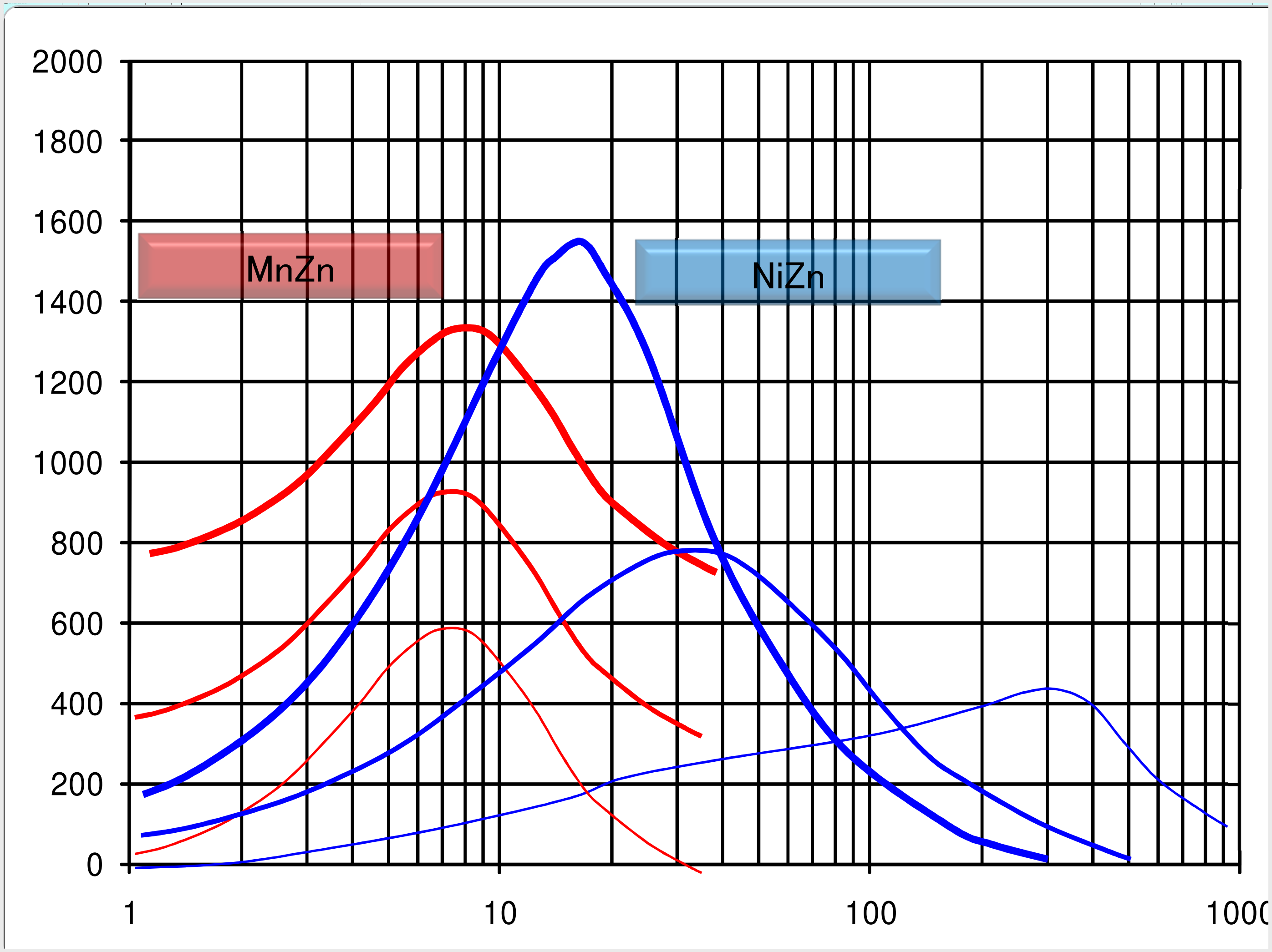
Clamp on Ferrites – Differential mode noise

- Can also be used as a differential mode filter.
  - In this example, it is single wire.

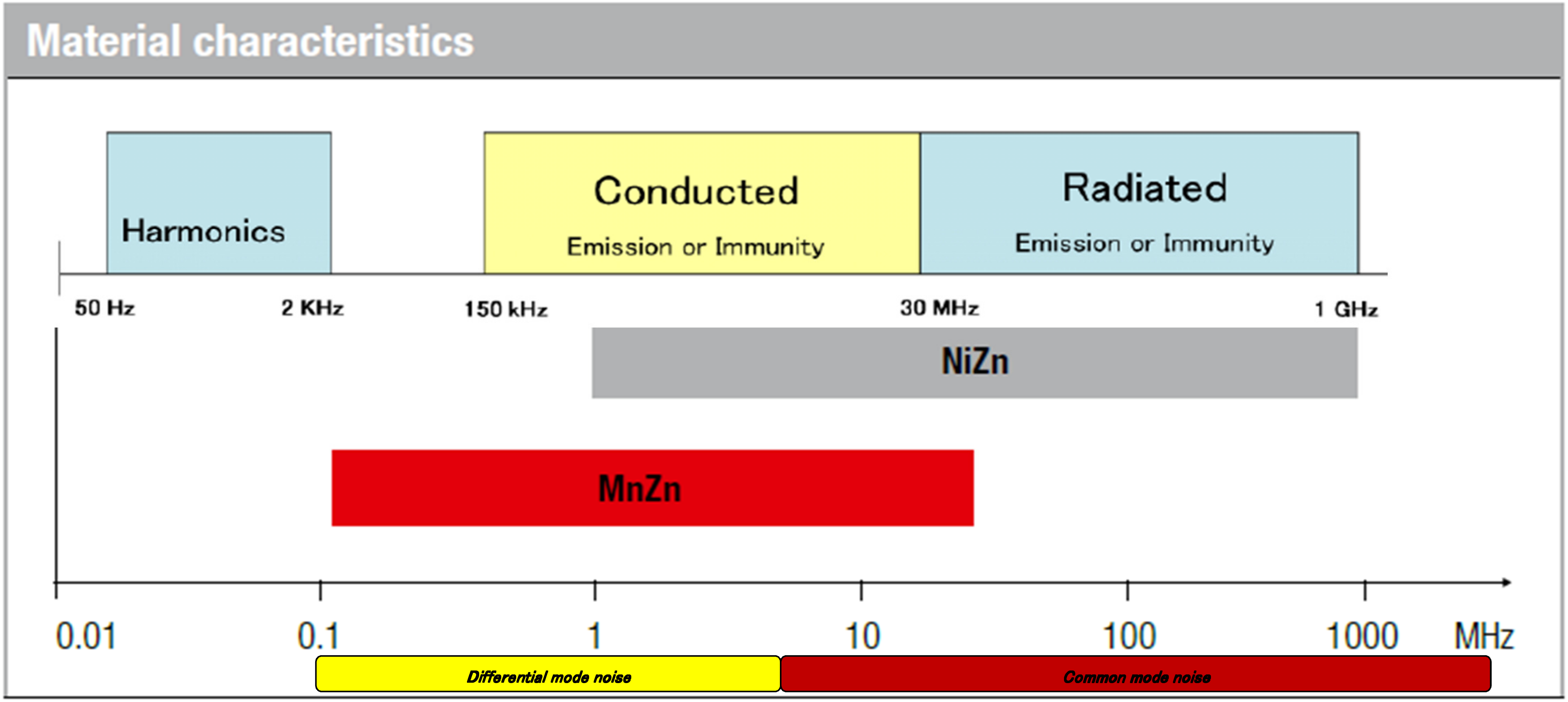


- **2 turns**

Clamp on Ferrites. Material Comparison



Clamp on Ferrites



How can we find out what interference we have?

Common mode or differential mode?

Take a Snap Ferrite and fix it on the cable (both lines e.g. VCC and GND)

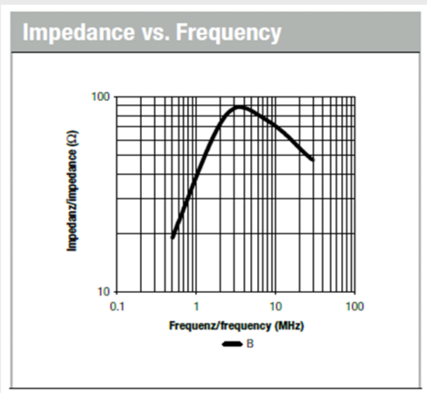
if noise is reduced or noise immunity is increased

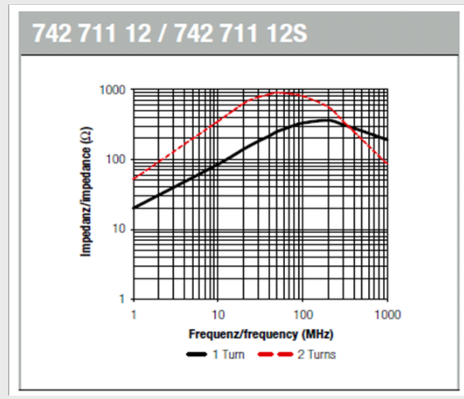
Common Mode interferences

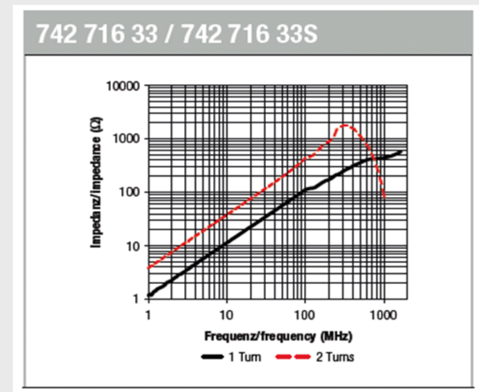
if not

Differential Mode interferences

Clamp on Ferrites







FIX – LFS	TEC / RING /FIX	GAP

- **STAR-GAP**

- Developed to increase impedance and to lower the suppression effect in the high frequency range with DC bias.

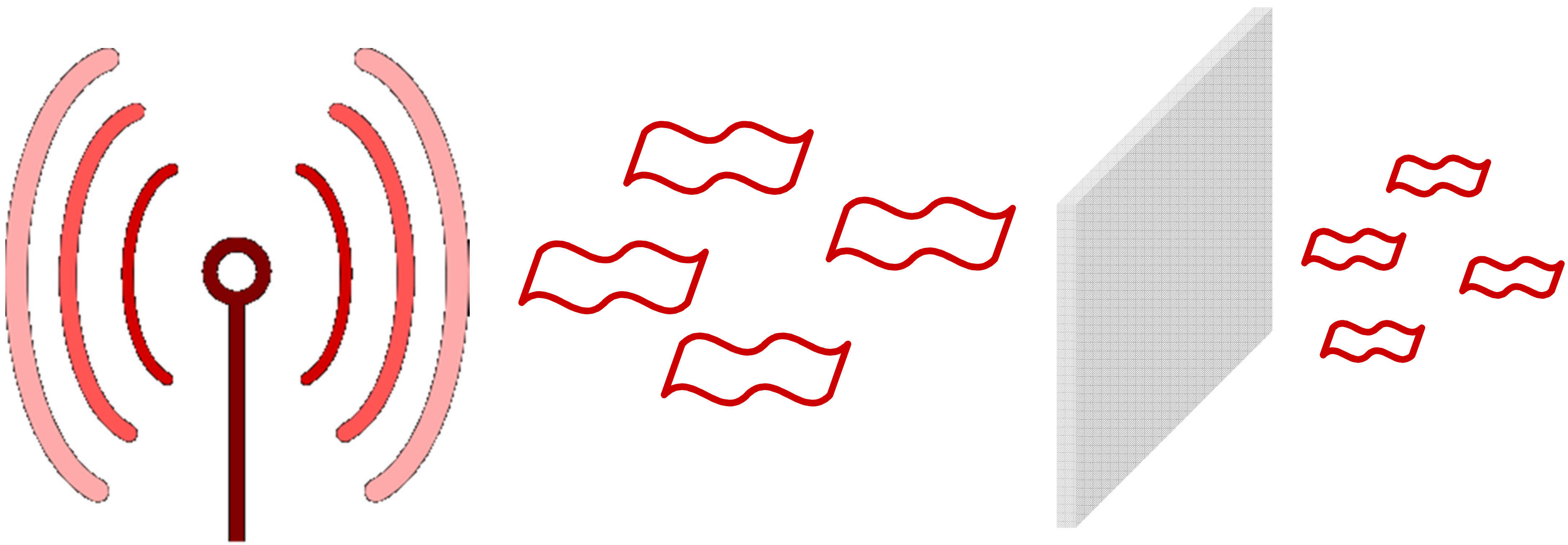
- Best performance with two turns.

- Very helpful in lowering EMI problems in frequency range of 100MHz up to 2.5GHz.

SHIELDS

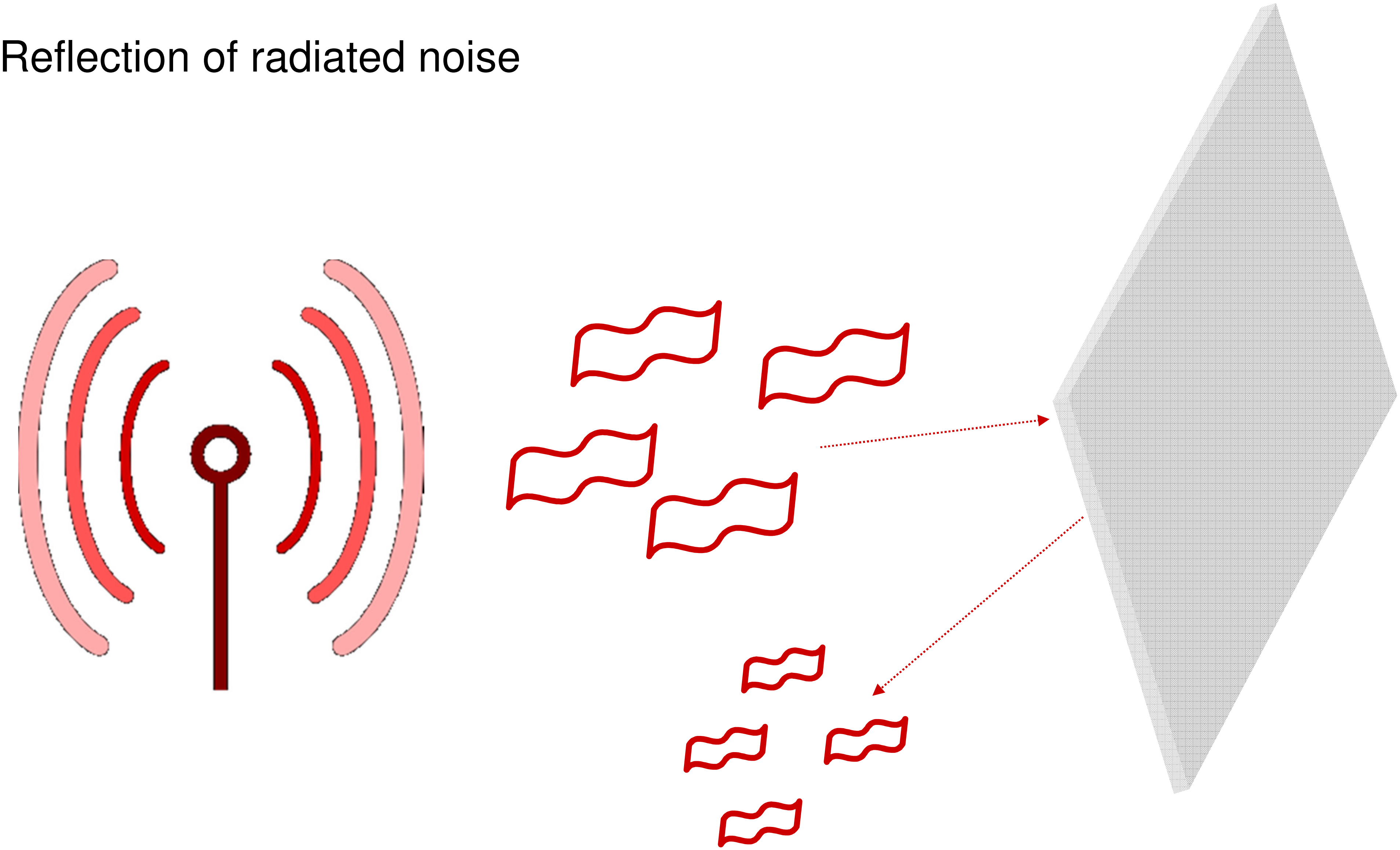
Radiated noise modes

Transmission of radiated noise



Radiated noise modes

Reflection of radiated noise



Electromagnetic wave

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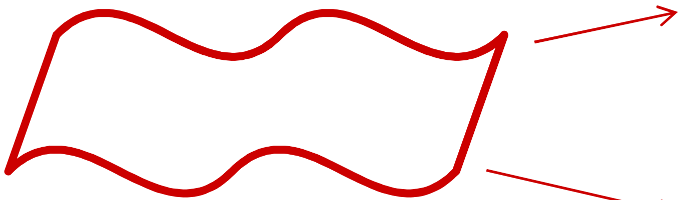
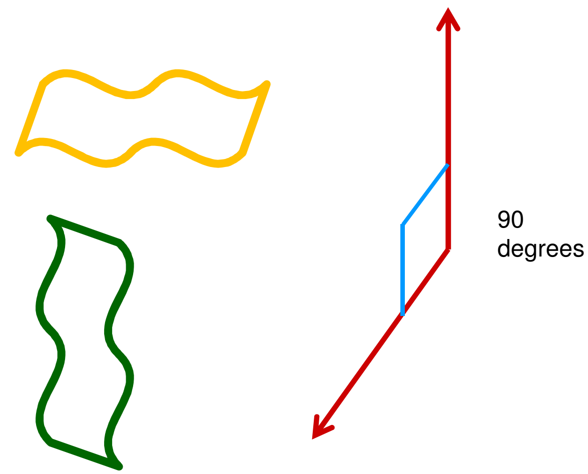
Components from a magnetic wave

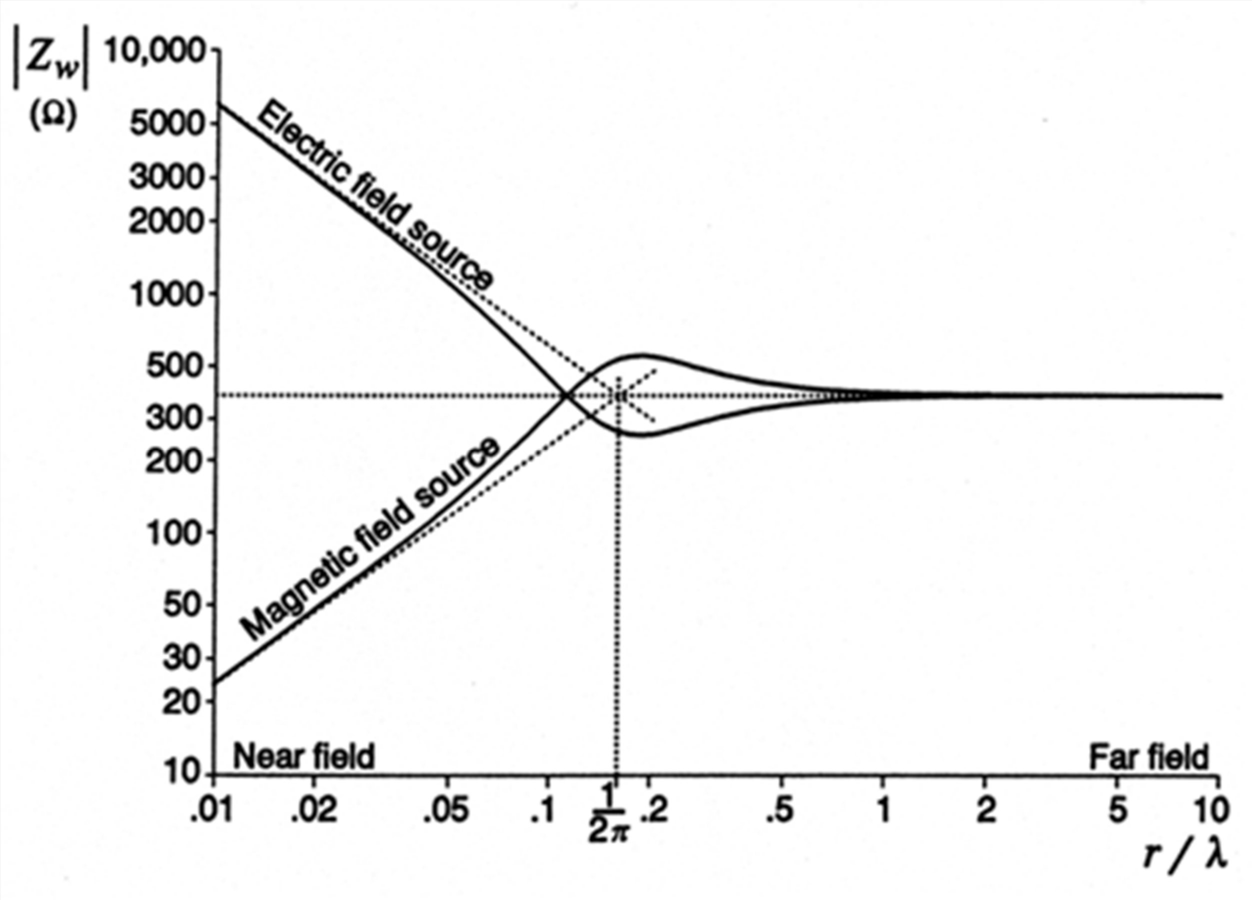


E electric field

H magnetic field



Near Field and Far Field



Enclosures

- Products can be built with two materials regarding RF:

1. **Metallic – Aluminium, steel, brass, copper.**

   Natural shielding materials

2. **Non metallic – Plastic, Nylon, Poliestyrene, PVC.**

   Materiais transparent to RF

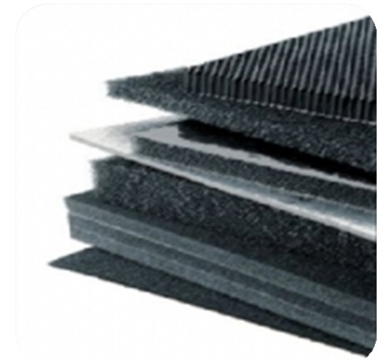
RF shielding types

Principal two type: **Metallic** (Cu, Al, Steel) and **Ferrite** (NiZn, MnZn or similar compounds)

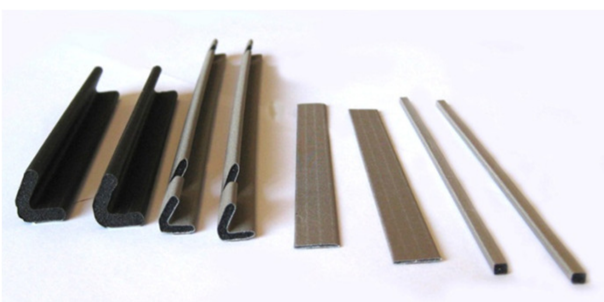
metallic shielding
WE-SHC

Absorber sheet
WE-FAS

Condutive gasket
WE-LTS



Condutive foam
WE-LS

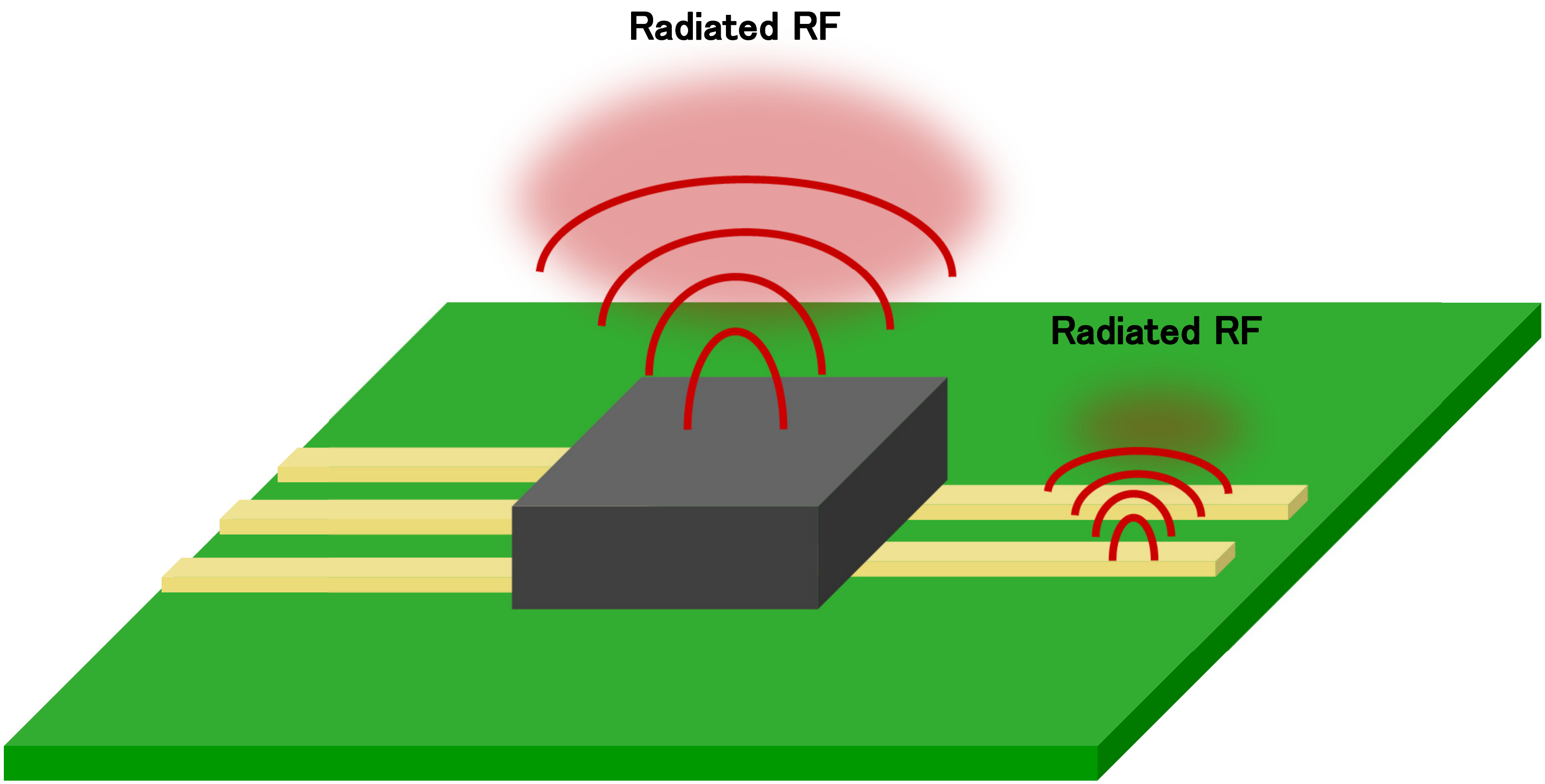


Condutive gasket
WE-LT

Condutive tapes
WE-CF/TS

Brooke Shields

Basic problem to be solved

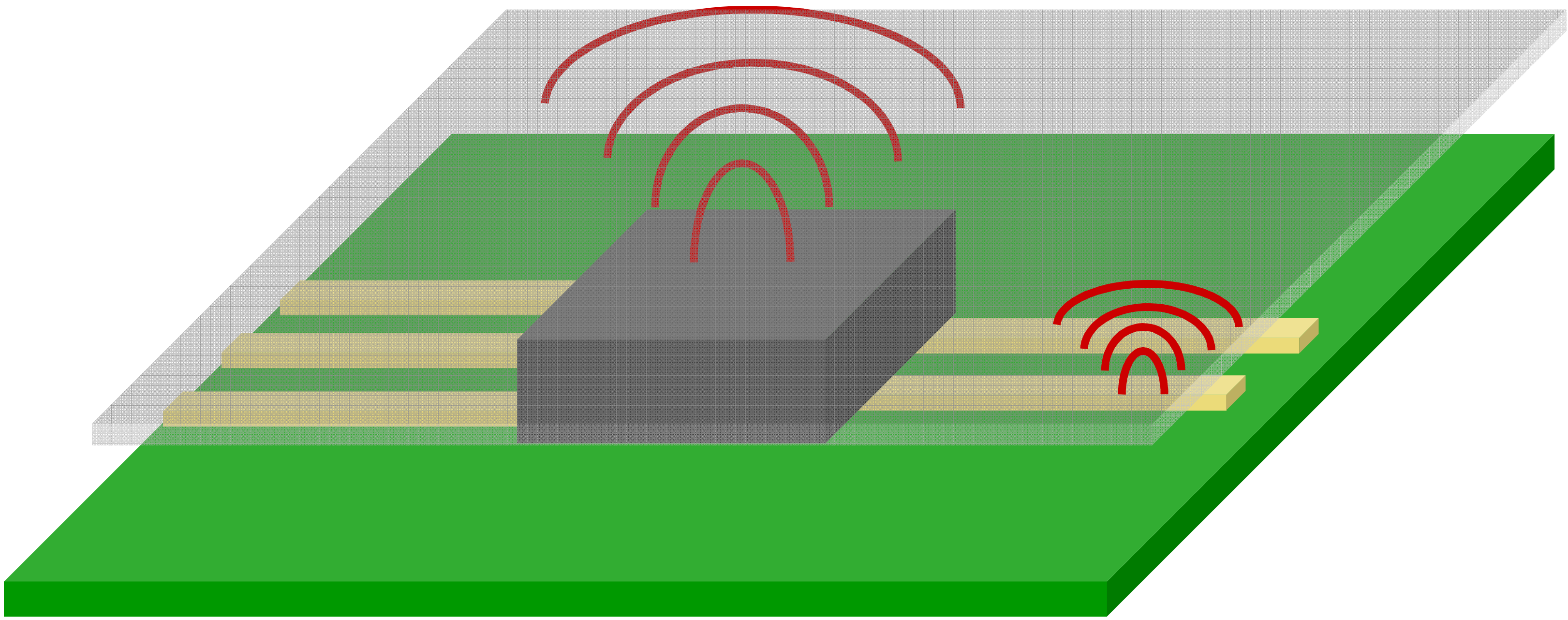


Applications (Shielding)

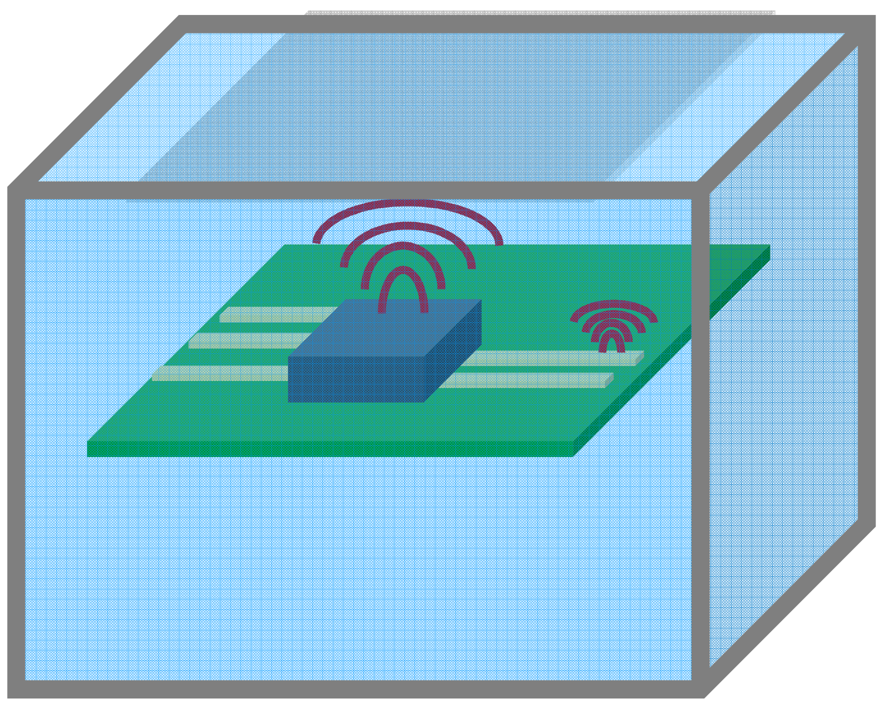
metallic

Ferrite

Application (Shielding components)

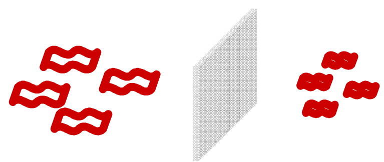


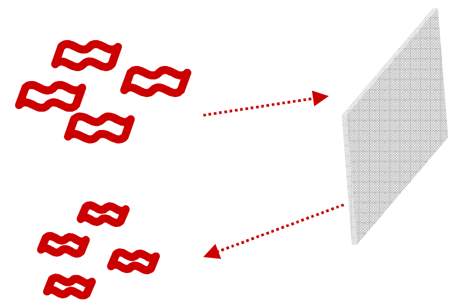
Application (shielding enclosures)



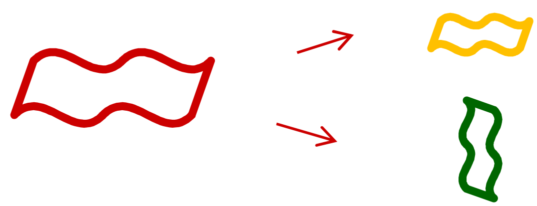
Revision

Two paths: transmission and reflection

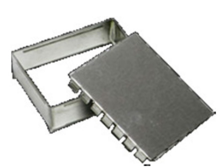




Two components E field and H Field

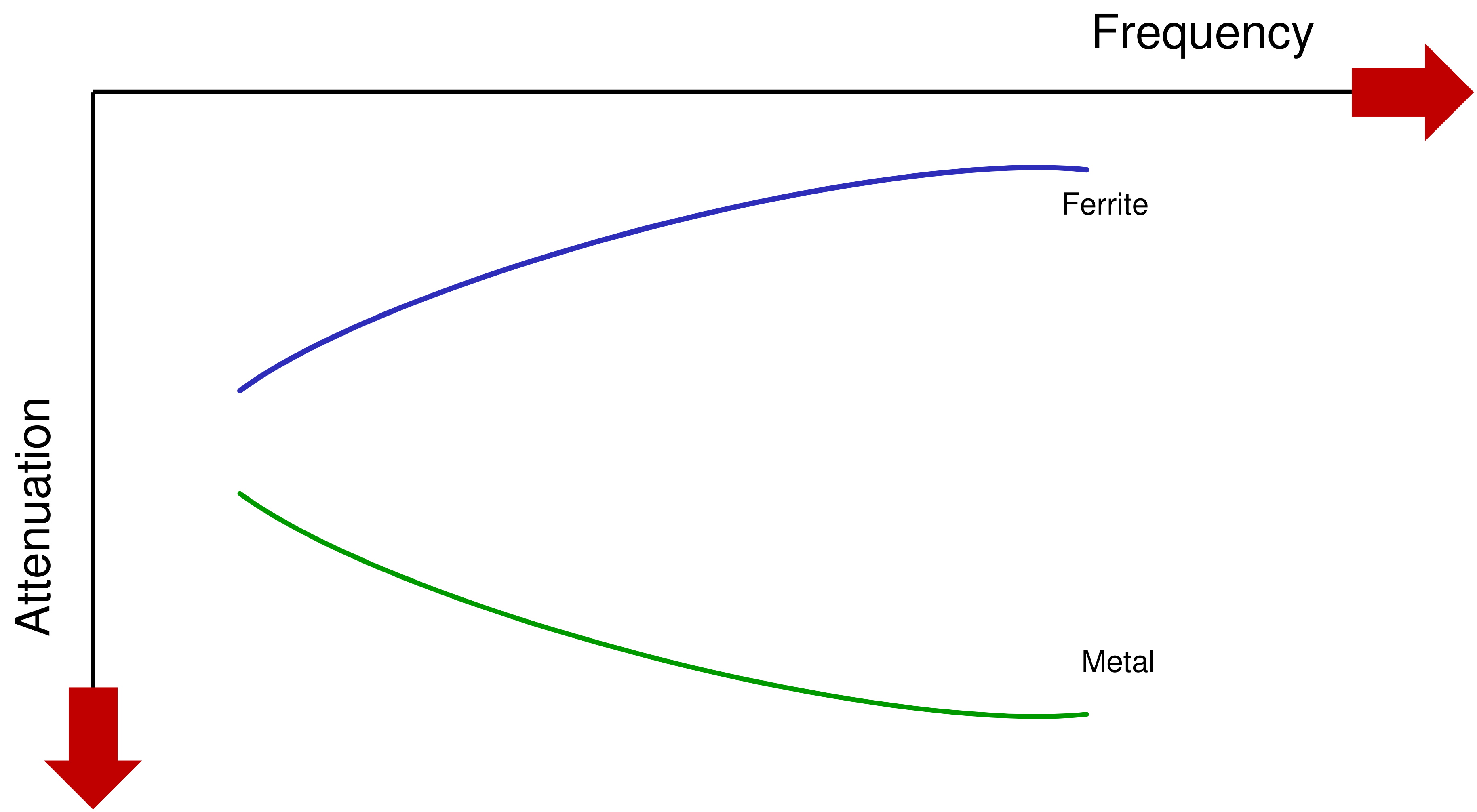


Two types of material



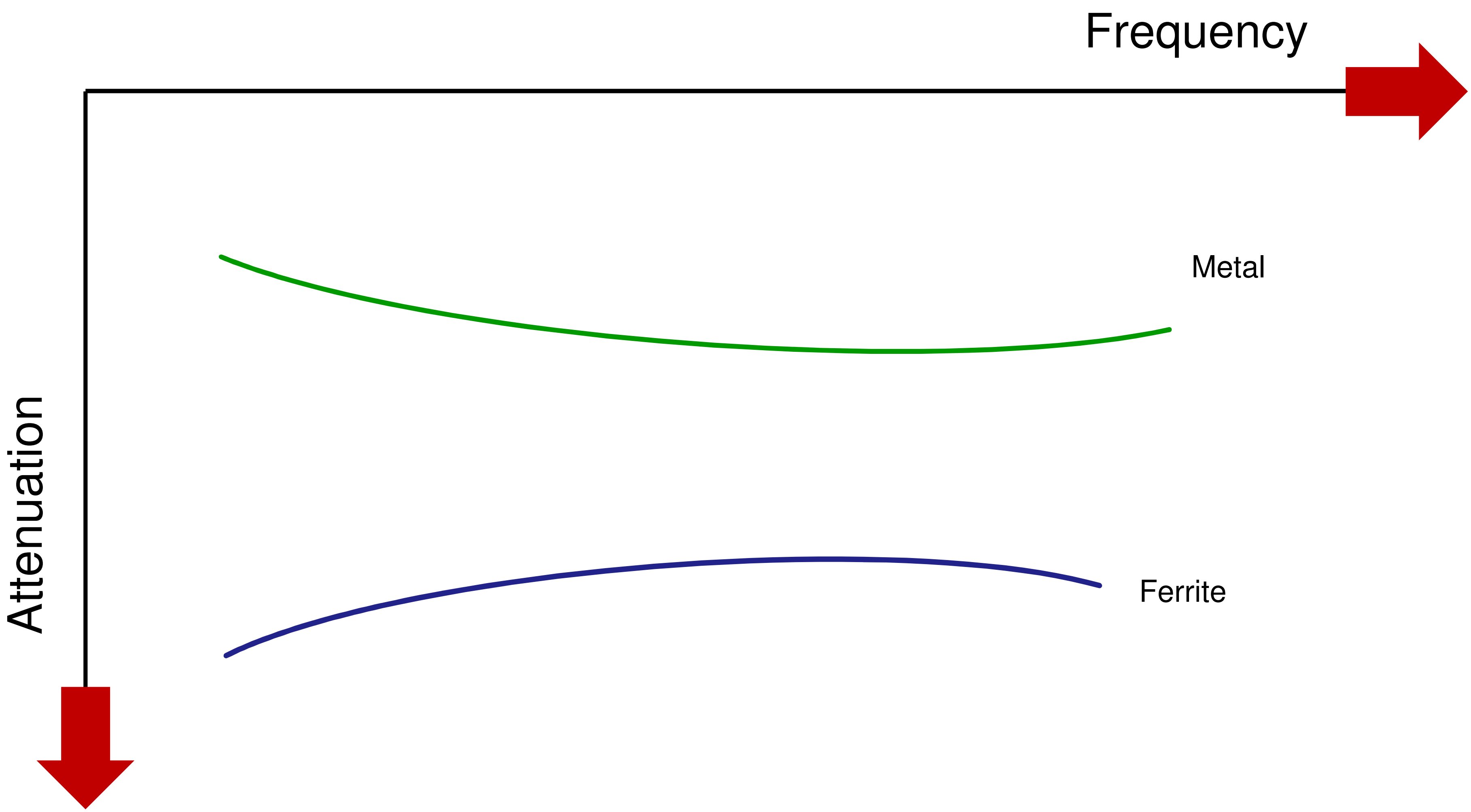
Material Behavior with Radiated Signals

Metal vs Ferrite when signals are transmitted

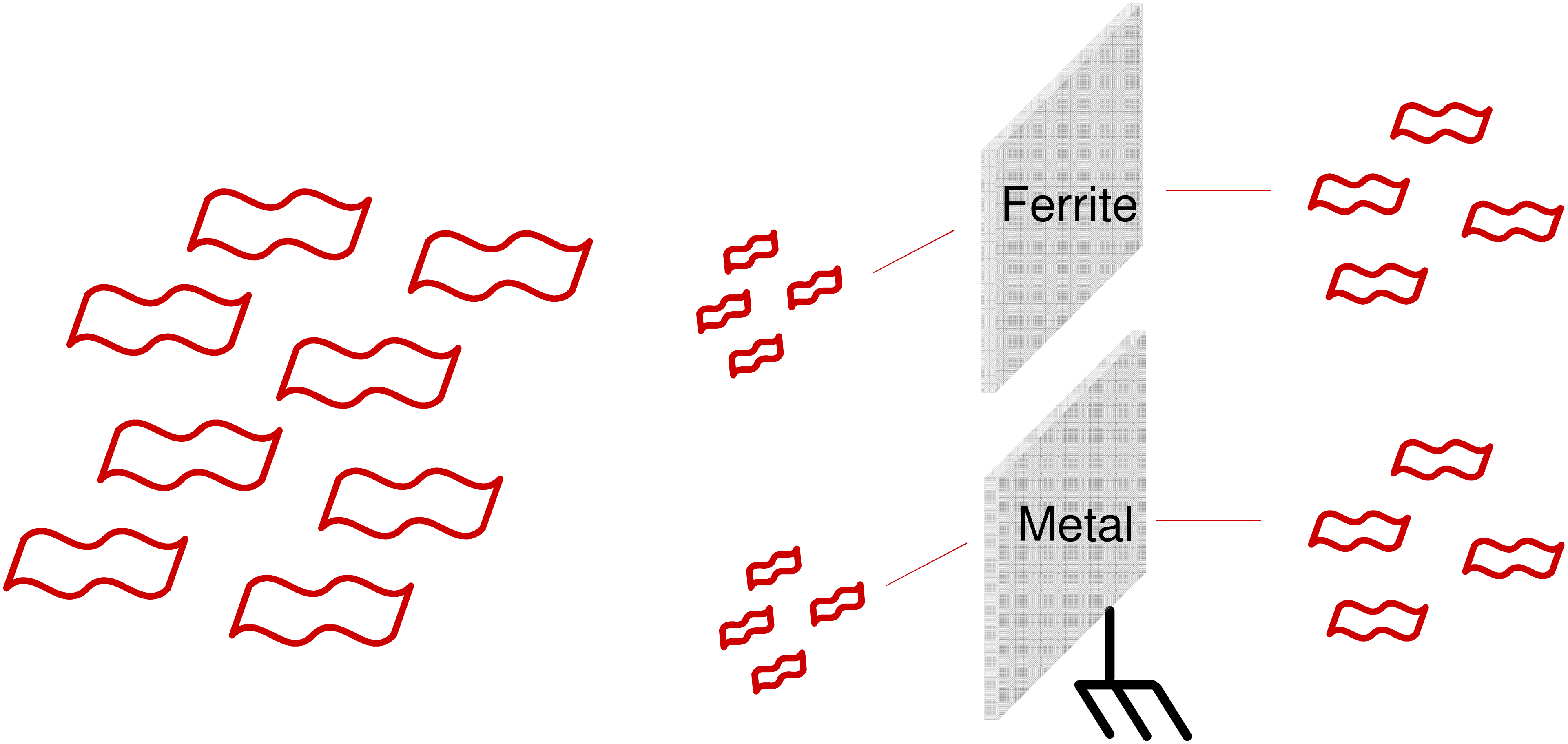


Material Behavior with Radiated Signals

Metal vs Ferrite when signals are reflected



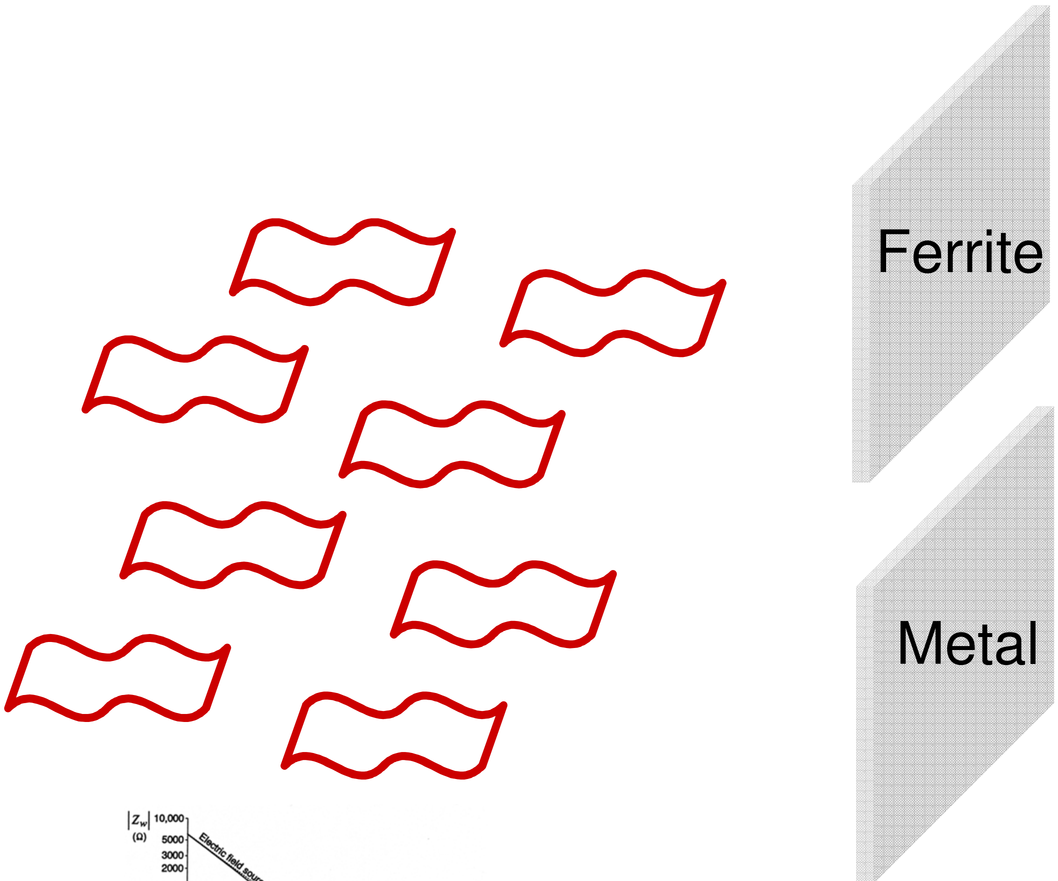
Advantages Metal vs Ferrite

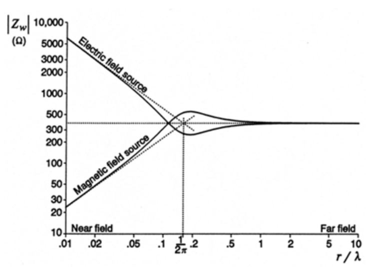


Metal has to be grounded! But a ferrite does not.

Metal is cheaper than ferrite and easy to find.

Shield Effect on Components of the EM Wave





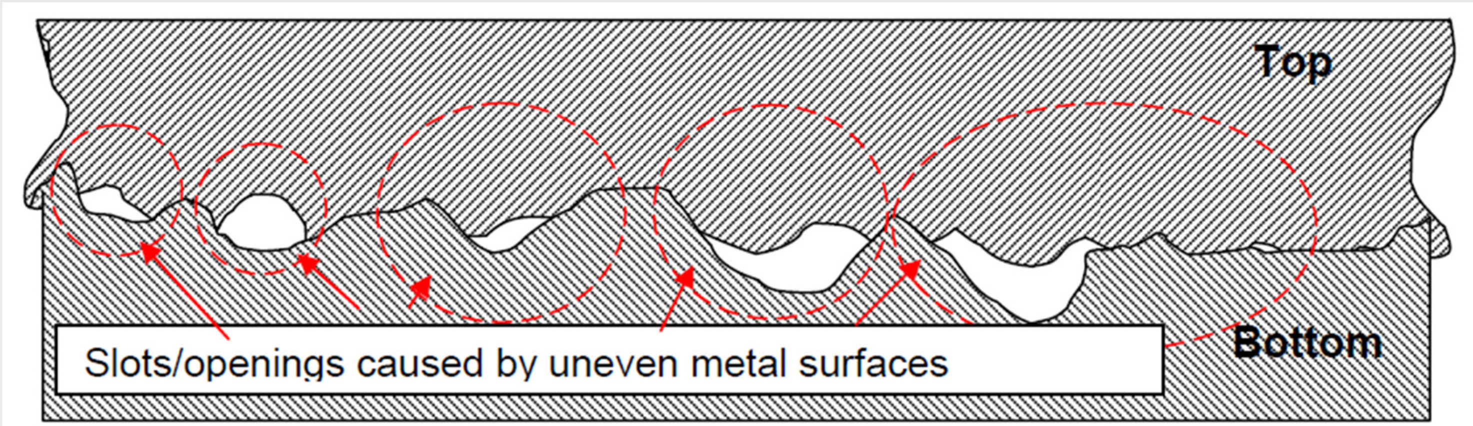
Ferrite works better at short distances and it affects more significantly the magnetic field

Metal works at any distance and it affects more significantly the electric field

Applications (scenario)

Metallic enclosure

Problems with metallic enclosures



- Gaps allow RF noises pass through.
- Slots can work as antennas

Antena WLAN 2,4GHz

$$\lambda = \frac{3\times10^8 \cdot m \cdot s}{2{,}4\times10^9 \cdot s}$$

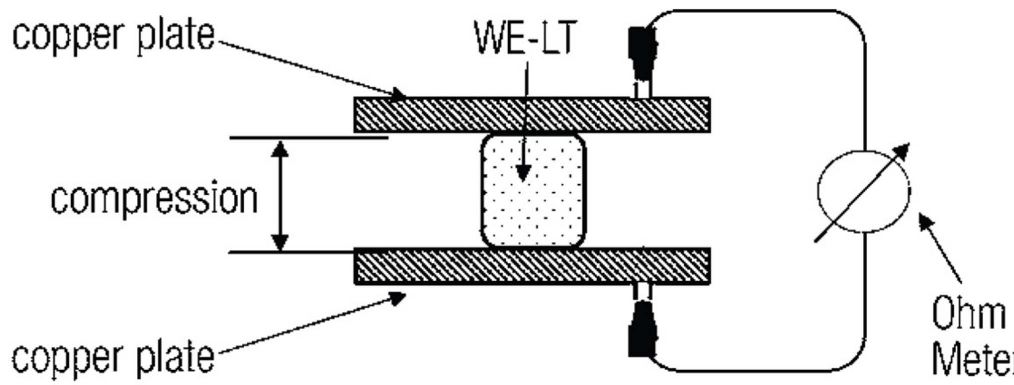
$$\lambda = 0{,}125m$$

$$\Downarrow$$

$$\lambda / 4 = 3{,}125cm$$

Metallic enclosures correctly grounded

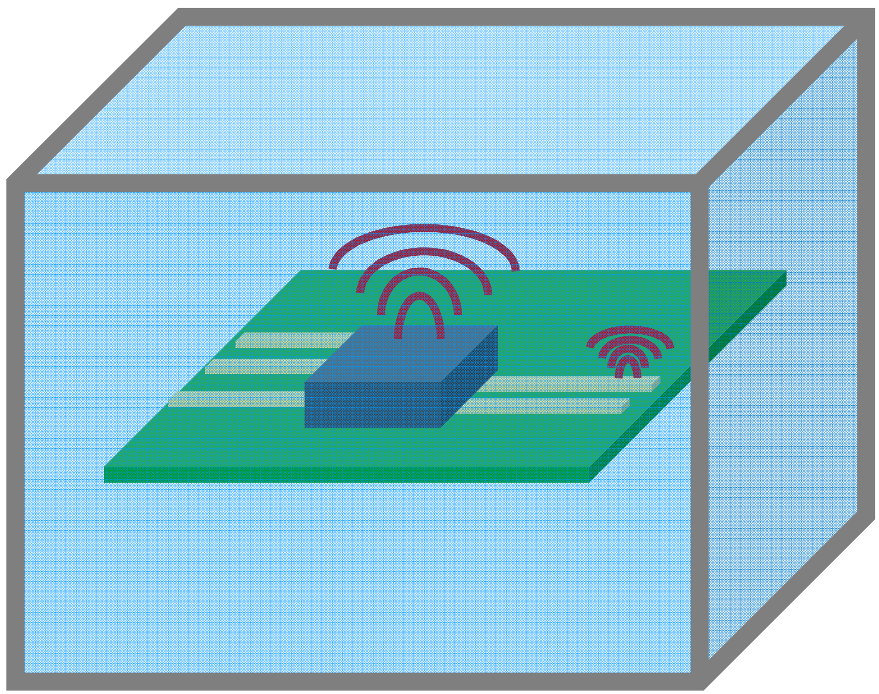
Gaskets and conductive tapes



Best gasket performance is when compressed by 50% to lowest impedance.

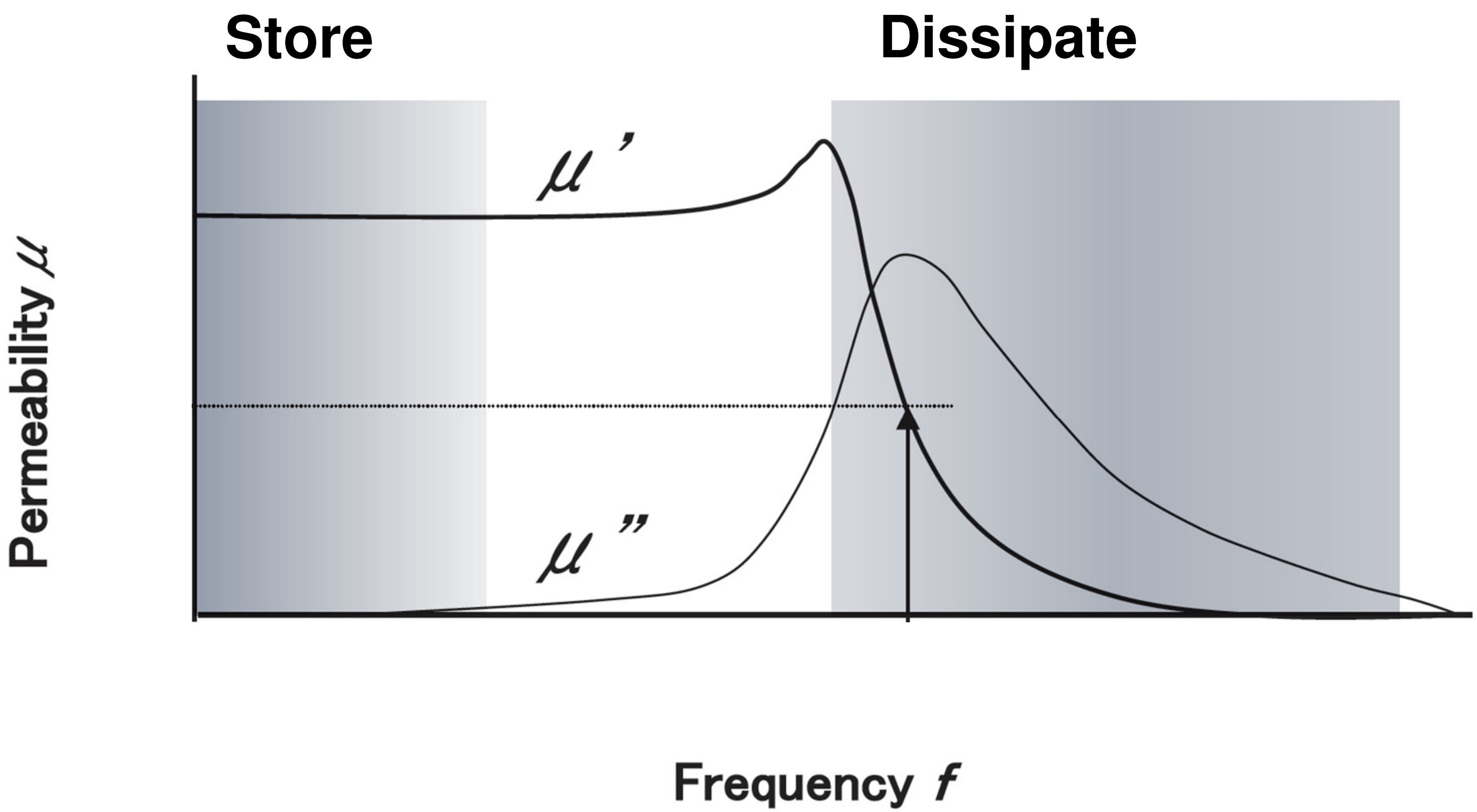
Applications (Gaskets)

Gaskets fill the gap between metallic walls from enclosure.



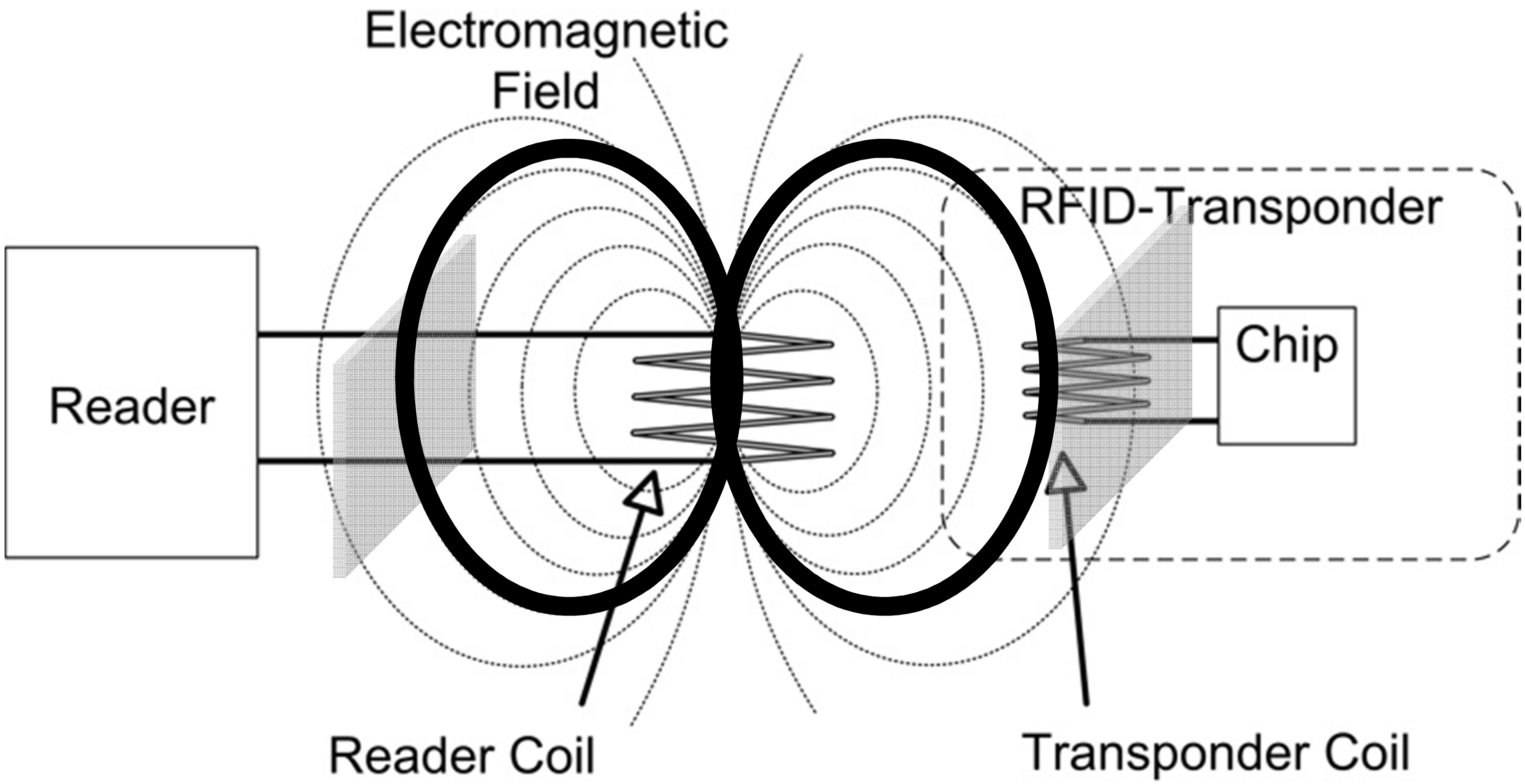
Ferrites characteristics:

Ferrites can store and dissipate



Application (Enhance RFID 13.56MHz)

Applications (Enhance RFID 13.56MHz)



What is best? Metal or Ferrite?

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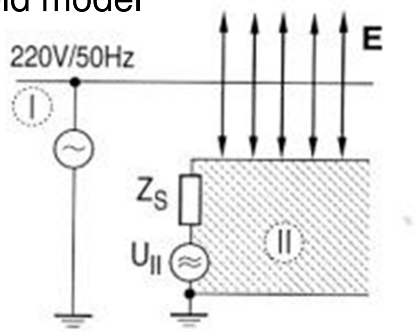
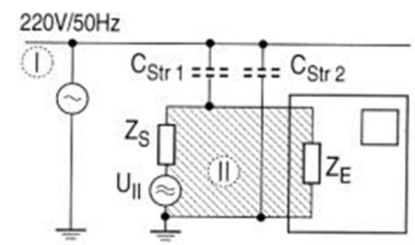
Capacitive coupling

Field model



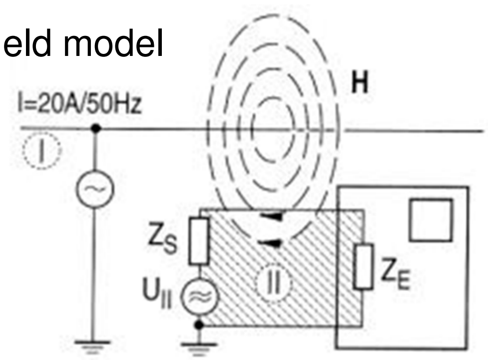
None

Network model



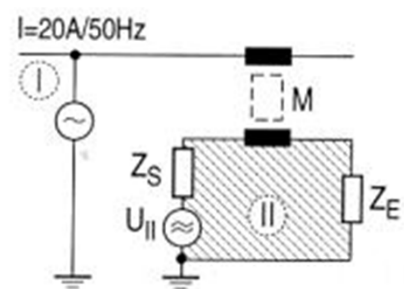
Inductive coupling

Field model



Ferrite

Network model



Q&A

http://www.we-online.com/

http://www.we-online.com/web/en/passive_bauelemente_-_standard/toolbox_pbs/Toolbox.php

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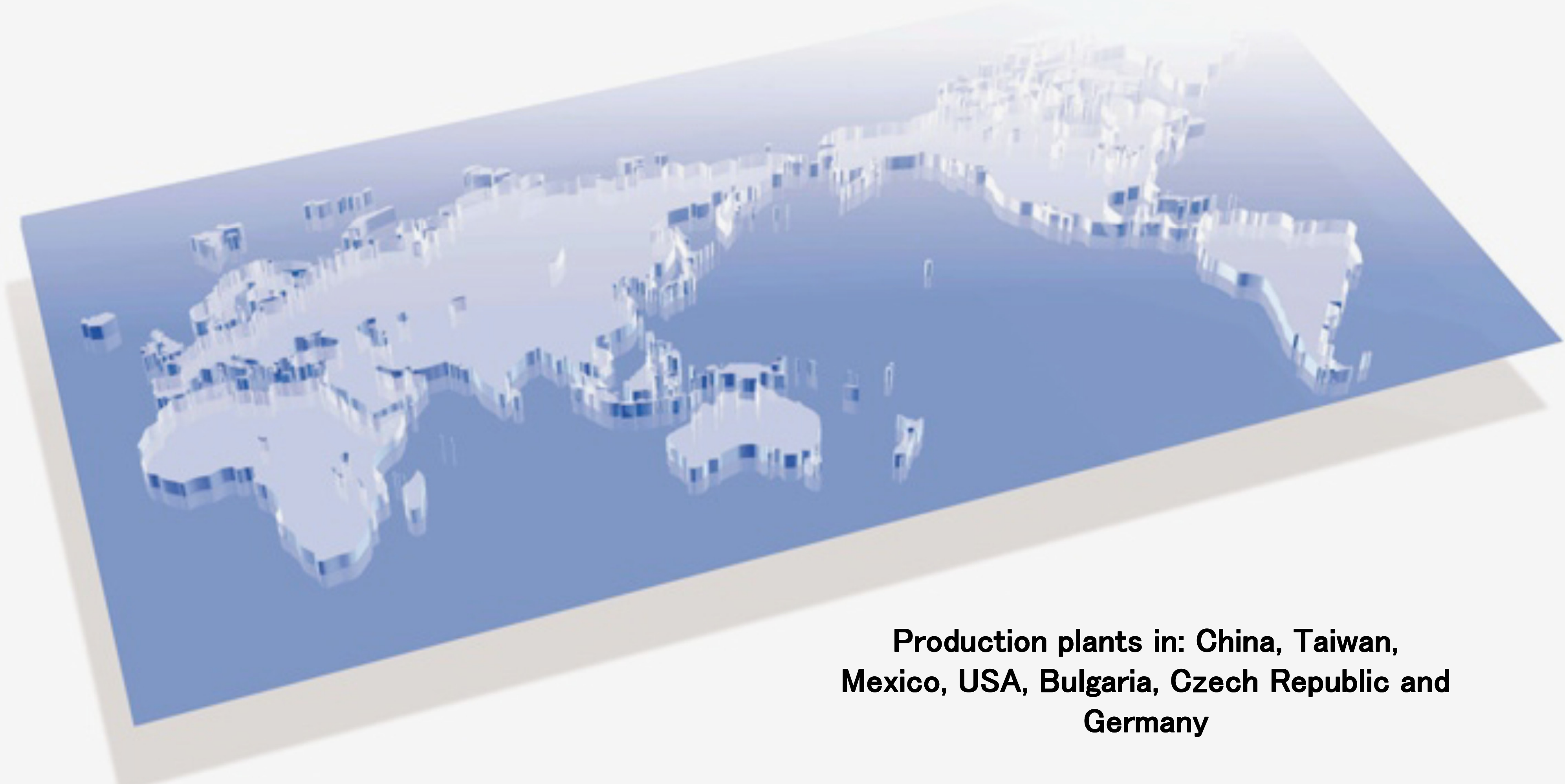


Production plants in: China, Taiwan, Mexico, USA, Bulgaria, Czech Republic and Germany

APPENDIX

EMC Overview

Conductive coupling

- Coupling path between source and victim is formed by direct contact.
  Example a transmission line, wire, cable, PCB trace or metal enclosure.

Capacitive coupling

- Electric field coupling.
  Occurs when a varying electrical field exists between two adjacent conductors.

Inductive coupling

- Magnetic field coupling
  Occurs when a varying magnetic field exists between two parallel conductors.
  Coupling between conductors causes parasitic induced voltages.

Radiative

- Source is the “transmitter” and victim is the “receiver”.

The Magnetic Field

The H field corresponds to what is called the magnetic field strength. It is measured in amps / meter (A/m).

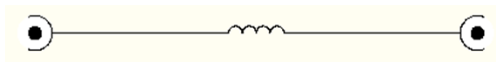
In free space or in air the B field represents magnetic flux density which is given in units of Tesla by B = μ_o.H where μ_o is the absolute magnetic permeability of free space $\mu_0 = 4\pi \times 10^{-7} \frac{N}{A^2}$

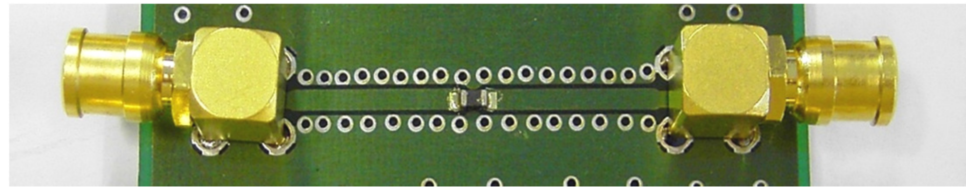
More magnetic flux can be produced by the same H value in certain (magnetic) materials, notably iron, and this is accounted by introducing another factor, the relative permeability μr, giving **B = $\mu_o \mu$ rH** for magnetic materials.

88

Filter topologies – L-Filter

- L-Filter

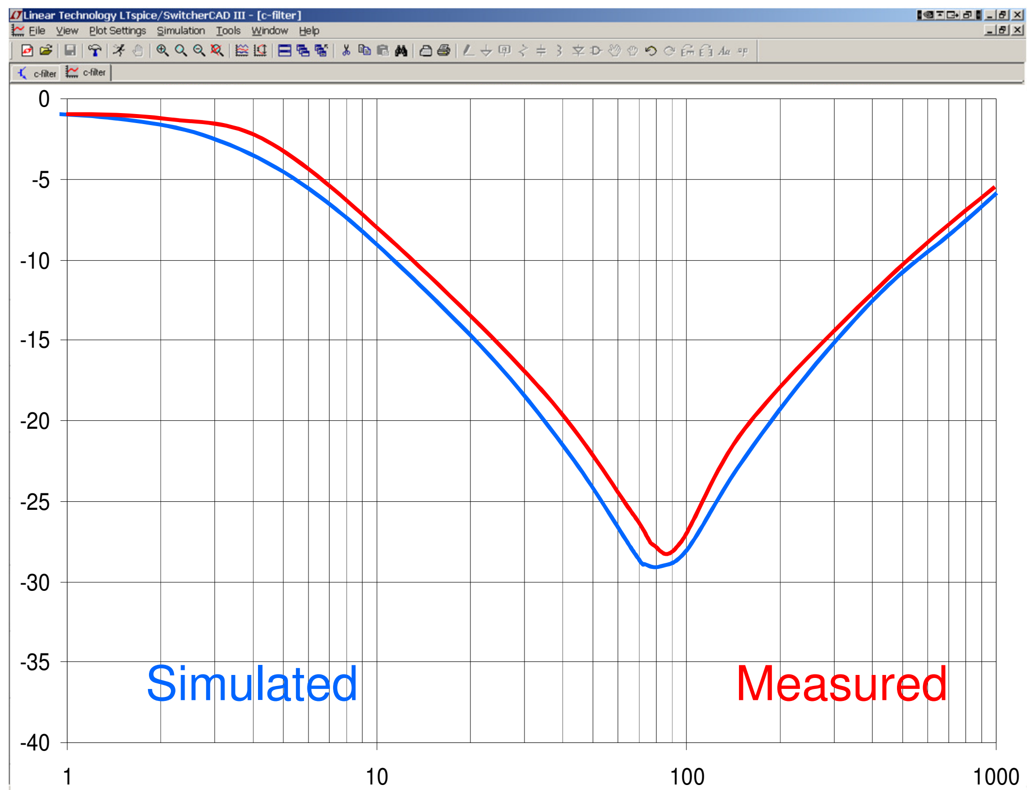




- instead of inductor use a SMD-Ferrite
- WE-CBF 742 792 093

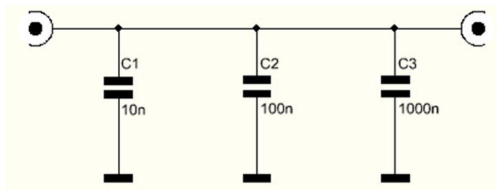
Z_{max}= 3000 Ω @ 80 MHz

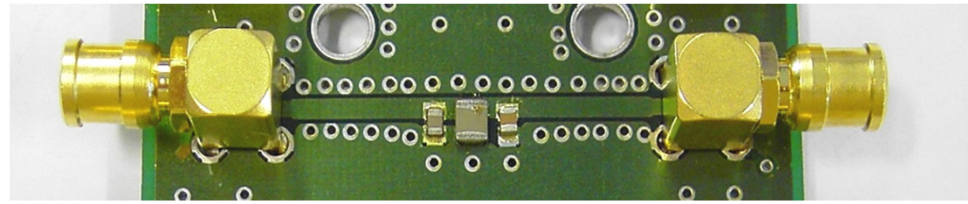
A_F = -29 dB @ 80 MHz



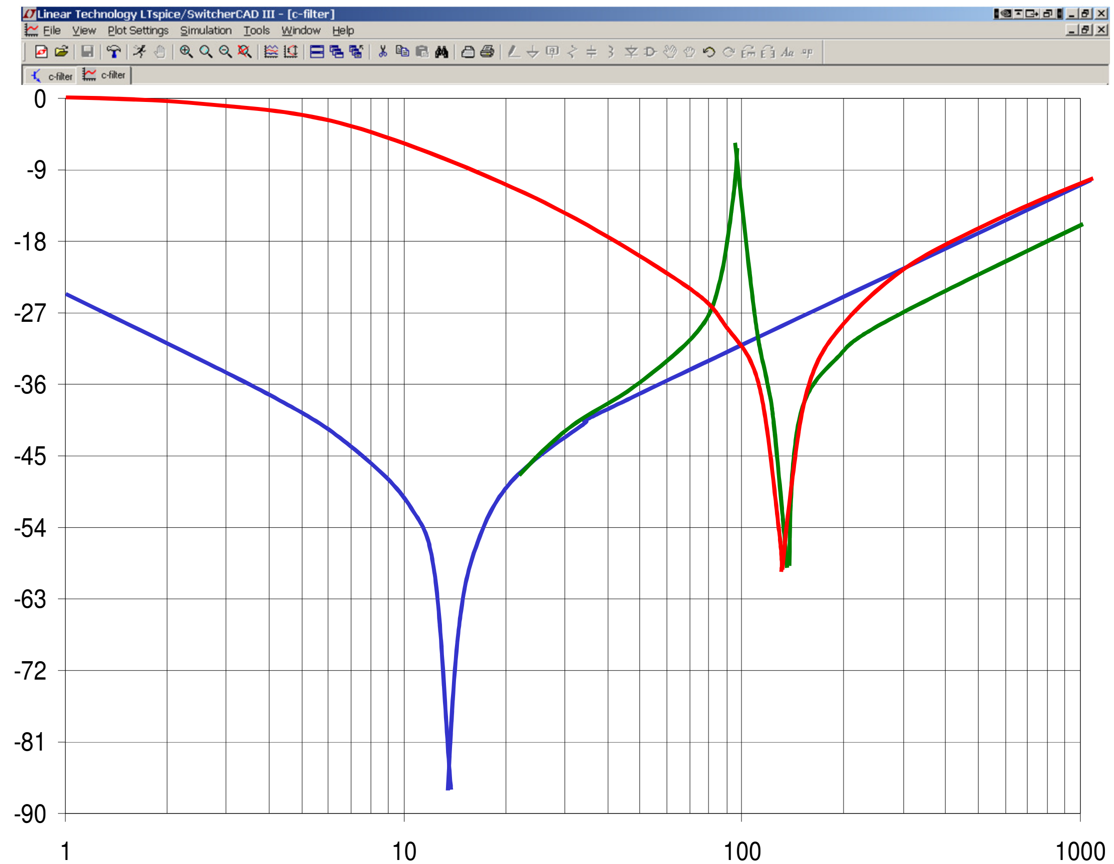
Filter topologies – Parallel-C-Filter

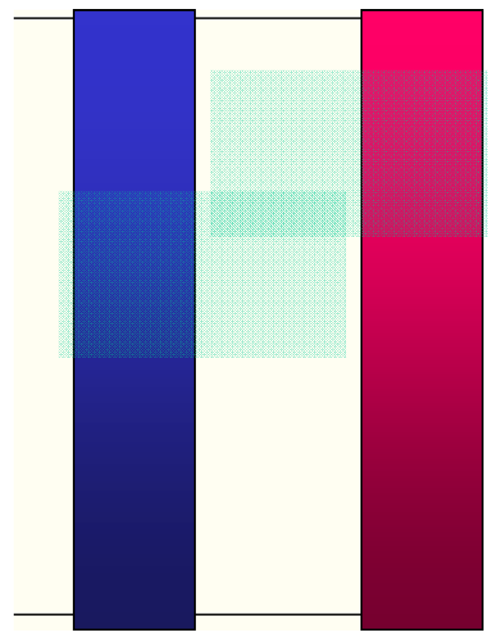
- Parallel-C-Filter





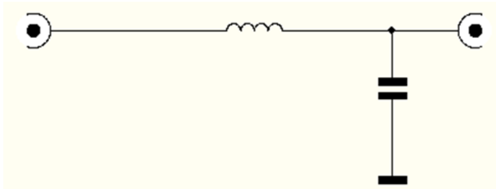
- resonance points

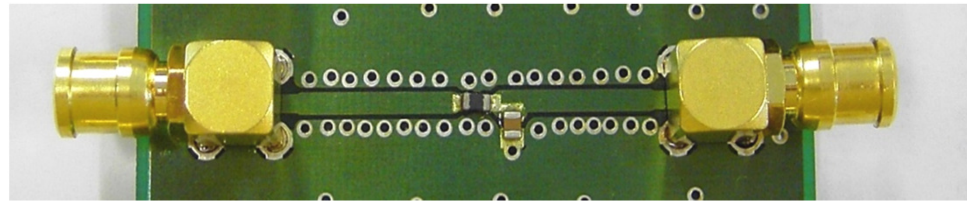




Filter topologies – LC-Filter

- LC-Filter

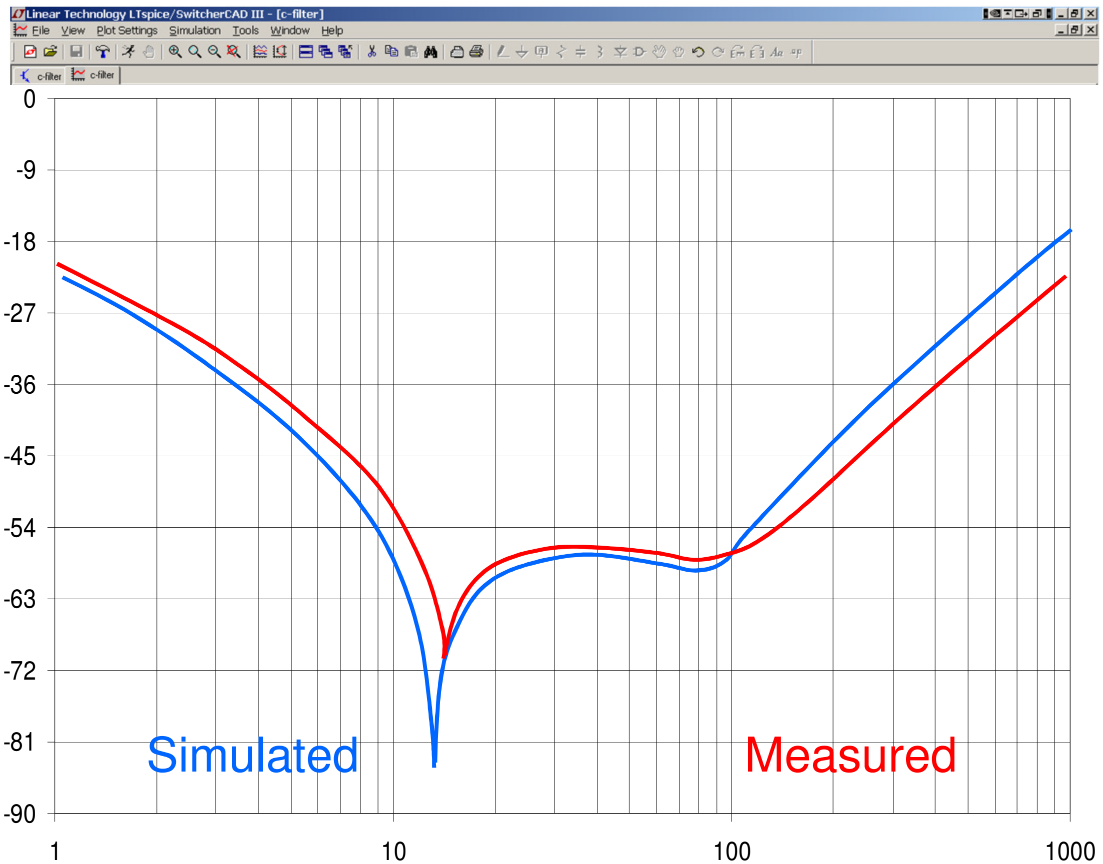




- Comparison simulated vs. measured

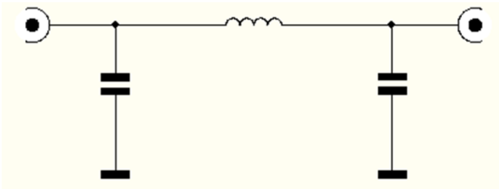
WE-CBF 742 792 093

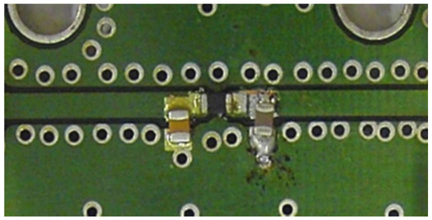
C=100nF



Filter topologies – PI-Filter

- π-Filter



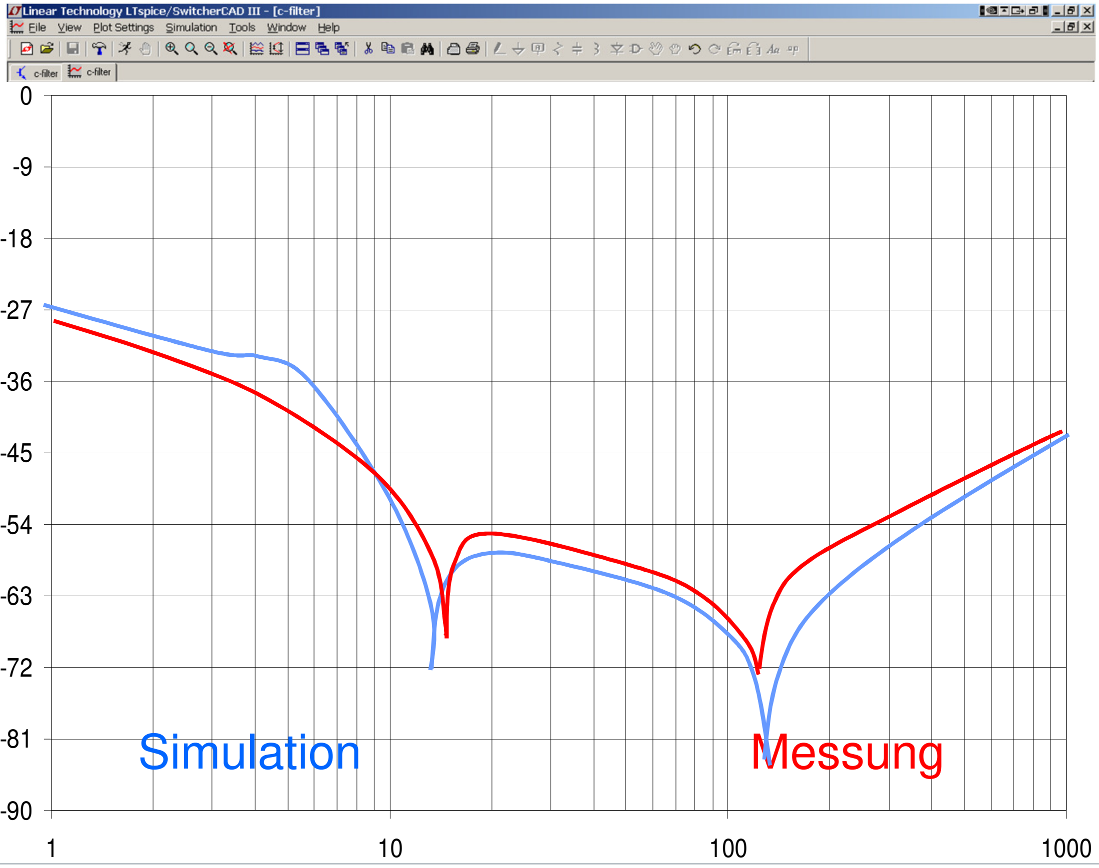


- Comparison Measurement - Simulation

WE-CBF 742 792 093

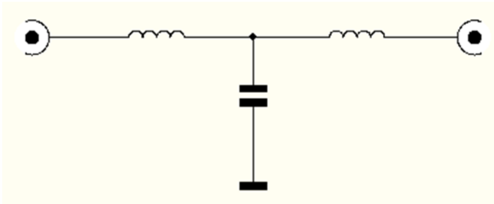
C_1=1nF

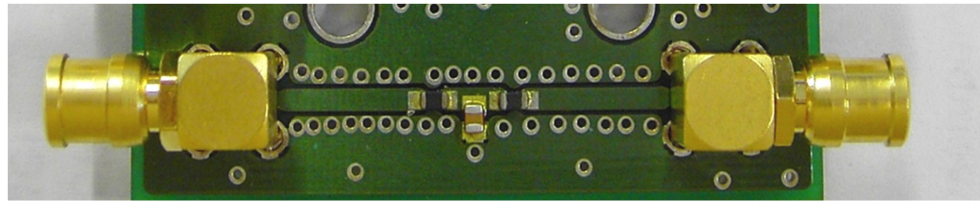
C_2=100nF



Filter topologies – T-Filter

- T-Filter



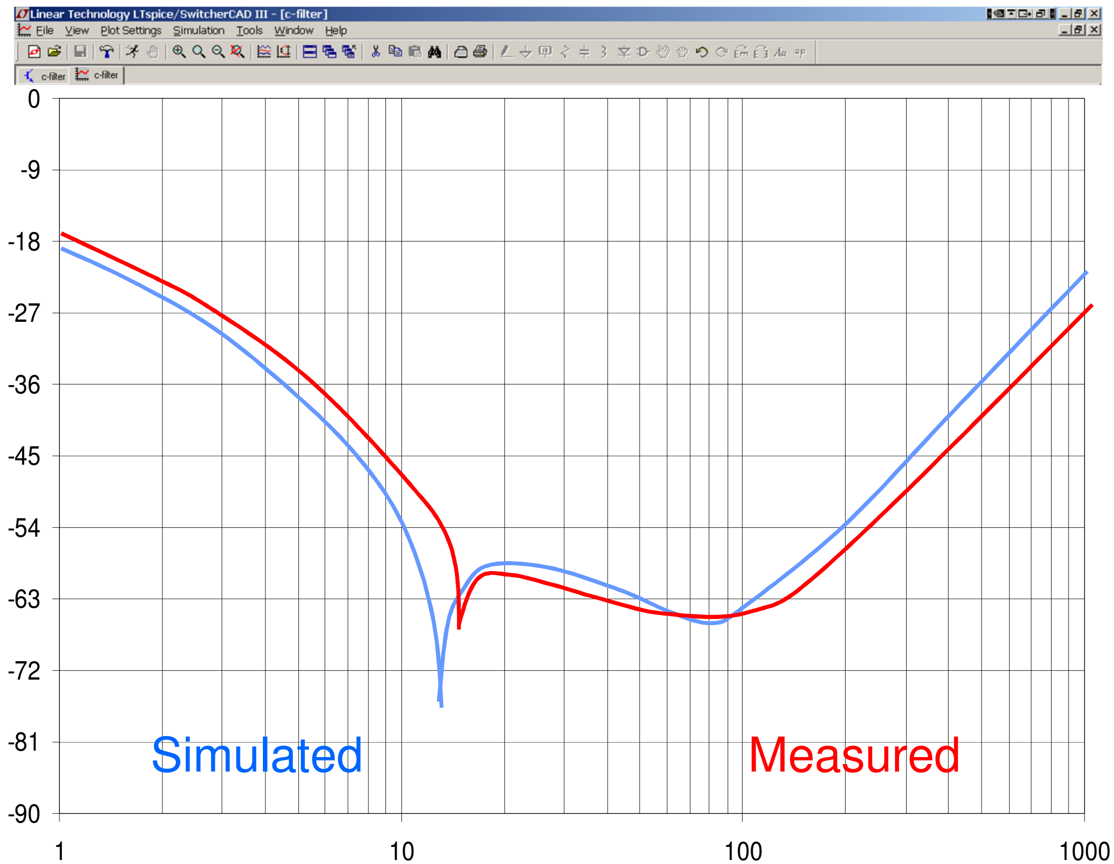


- Comparison simulated vs. measured

C=100nF

L_1=742 792 040

L_2=742 792 093



Soft ferrites (Typical permeability values)

• Iron power / Superflux :	50 ~ 150
• Nickel Zinc :	40 ~ 1500
• Manganese Zinc :	300 ~ 20000

The Magnetic Field

WÜRTH ELEKTRONIK

The H field corresponds to what is called the magnetic field strength. It is measured in amps / meter (A/m).

In free space or in air the B field represents magnetic flux density which is given in units of Tesla by $B = \mu_o.H$ where μ_o is the absolute magnetic permeability of free space $\mu_0 = 4\pi \times 10^{-7} \frac{N}{A^2}$

More magnetic flux can be produced by the same H value in certain (magnetic) materials, notably iron, and this is accounted by introducing another factor, the relative permeability μr, giving $\mathbf{B = \mu_o \mu rH}$ for magnetic materials.

Thank you